THE

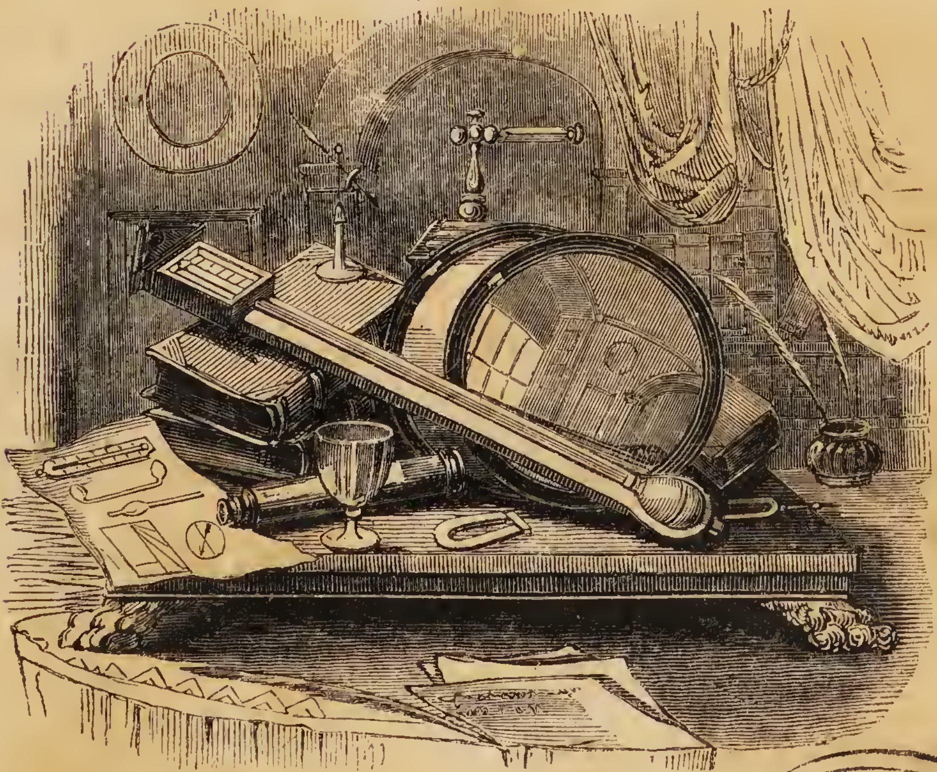
STUDENT'S MANUAL

OF

NATURAL PHILOSOPHY.

BY

CHARLES TOMLINSON.



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TO

THE RIGHT REVEREND

EDWARD DENISON, D. D.,

LORD BISHOP OF SARUM.

My Lord,

The zeal with which your Lordship encourages all good and useful pursuits, makes me anxious, as a teacher of youth, to connect one of the subjects of my instruction with your Lordship's name.

If I have succeeded, in the following pages, in explaining and illustrating some of the most beautiful laws which God has ordained to regulate the action of the material world,—in such a manner as is calculated to awaken in the student's mind, emotions of love and gratitude towards Him,—your Lordship will not have to regret the gracious permission given me to dedicate this Manual to your Lordship.

That your Lordship may long continue to be a promoter of Christian holiness in the high station to which Providence has called you, is the earnest desire of

Your Lordship's

Respectful and obedient humble Servant,

C. Tomlinson.

Salisbury,
28th September, 1838.

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PREFACE.

As this Manual of Natural Philosophy differs in arrangement and style from other works on the same subject already before the public, it is necessary to explain the objects proposed in offering to the student this work in its present form.

This volume originated in a series of treatises on *Scientific Instruments*, several of which the Author contributed to the *Magazine of Popular Science*. A subject being chosen, was divided into two or three sections; the first section containing an account of the natural phenomena which regulate, not only the instrument under consideration, but a large variety of kindred processes in science, art, and industry generally: the second containing an account of the instrument itself; the history of its invention; its variations and improvements from time to time, and the methods of using it; so as to elicit the facts from which the laws of Nature are deduced; describing, in short, the method in which the working-tools of the philosopher are made and successfully applied: the third section (when such has been found necessary) containing a direct application of the instrument to particular inquiries.

This Manual, as its title implies, professes to supply the wants of the early *student*. The Author has been engaged for several years in the duty of imparting scientific instruction to his pupils in such a manner, as to avoid the two

extremes of the merely *popular* and the strictly *mathematical.* A mean between the two has been adopted with satisfactory results, and the present work is offered as a specimen of such instruction. A merely popular work may be read for *amusement:* a strictly mathematical work suits those few only whose ample means and whose previous training induce them to devote all their energies to the highest departments of a particular study. For those who would combine amusement and instruction, a mixed mode is necessary, such as will enable the student to appreciate not only *facts*, but also the modes in which those facts have been observed; by what processes of reasoning deductions have been made; and the degree of certainty with which we may admit them.

To supply all this, in a moderate degree, is the object of the present work, which is adapted to the comprehension of an extensive class of students, whether young persons under the direction of a tutor; or those of a more advanced age, who depend on their own exertions for the acquisition of the principles of physical science. This Manual may serve as a Reading or Class-Book for Schools, as well as for the general reader. Those who are unskilled in the language of mathematics will receive with pleasure, under an easy form, truths, otherwise inaccessible to them. The Author, therefore, has been careful to avoid all, but easy computations. He has introduced only such as will tend to excite the attention without wearying it; thereby giving an additional value to the subject under investigation by supplying elementary methods of proof, which the student may, according to his inclination or ability, follow out to a fuller extent, by reference to the works of our first scientific authorities.

It has been the aim of the Author to introduce in the present volume as many subjects only as could be treated of in a full and satisfactory manner, within the compass of one volume. He has not been anxious to supply a *complete* work on Natural Philosophy within these limits; such would necessarily have been meagre, and unprofitable to the student. Certain prominent subjects have, therefore, been selected, with which it behoves every one to be acquainted; such, for example, as relate to what may be called our HOUSEHOLD INSTRUMENTS, *viz.* the Thermometer, the Barometer and Vernier, the Hydrometer, the Hygrometer, the Tuning-Fork, Musical Glasses and Music generally, the Compass, the Prism, the Telescope and the Sun-Dial: these subjects, and those in immediate connexion with them, such as refer to aëriform and liquid bodies, are treated of somewhat extensively. The subject of Mechanics, treated as such, the Author has not entered upon. Those, who wish to investigate this branch of Natural Philosophy, are referred to the excellent work of Professor Moseley on *Mechanics applied to the Arts.*

C. T.

SALISBURY,
September, 1838.

NATURAL PHILOSOPHY.

INTRODUCTION.

And yet was every faltering tongue of man,
Almighty Father! silent in thy praise:
Thy works themselves would raise a general voice,
E'en in the depth of solitary woods
By human foot untrod; proclaim thy power,
And to the quire celestial Thee resound,
The eternal cause, support, and end of all.—THOMSON.

1. MAN, as he is situated on the globe which he inhabits, is subject to all the physical laws which, under the direction of a superintending Providence, govern the universe. He is endowed with certain senses, whereby alone he acquires all his perceptions and all his early knowledge. The senses are the means, by which the sentient principle within us, communicates with the external world. They convey to the understanding, information, which the judgment corrects and the imagination combines; and this correction becomes more extended, and is oftener applied, in proportion to the healthy discipline to which the higher faculties of the mind have been subjected. The sublime truths which the science of Astronomy reveals to the philosopher, are, to the man uneducated in the ways of Nature, but so many objects of wonder; and it is only after long and close application, that the latter can be brought to admit principles, which seem to run counter to the evidence of his senses. But the mind accustomed to view the works of God as the productions of an infinite, all-powerful, and beneficent Being; the mind schooled and disciplined by the proper exercise of its nobler faculties, receives the evidence which the external senses offer, and presents it to the judgment, which corrects and

modifies it in a variety of ways, so as to prevent the many illusions to which the senses are subject.

2. Man, therefore, is a creature of sense only in part: when he exercises the powers of his mind, it is not necessary that he should constantly exercise his external senses. He is gifted with memory, as well as with perception; so that he draws, as from a vast store-house, the acquired knowledge which is founded upon the corrected perceptions of past years. Wonderful and mysterious does this power present itself to our contemplation; a power which contributes to form the felicity of the good and the wise; as it is often the curse of the wicked and depraved: the former desires to strengthen and perpetuate a gift which ministers to pleasures the most innocent, and to desires the most exemplary; while, for the latter, there is no Lethean cup wherein "to steep the senses in forgetfulness;" seldom an ennobling faculty which prompts its owner to regard life as the valuable boon, which it appears to be to the cheefrul mind of the Christian philosopher.

3. How perfectly and how completely do the mind and the senses act independently of one another in processes purely mental; and how obedient are the senses to the call of the higher powers when their services are required! If the mind were to estimate the processes by which the eye conveys the impress of external objects,—to trace the progress of individual rays to the cornea,—their refraction through the membranes and humours of the eye, as far as the picture on the retina,—and then to follow the impulse along the optic nerve until that impulse terminated we know not where:—if the mind were to estimate the process by which the ear participates in the vibrations of the external air, and to trace those vibrations from the membrane of the tympanum, along a chain of little bones, to a series of canals, wherein the auditory nerve is waiting to convey, in its own perfect but mysterious manner, some information to the mind as derived from the sounding body:—were it the office of the sentient principle within us to take cognizance of all these processes, we may conceive how slow and toilsome, constituted as we are, would be the perception of objects as well as the conception of ideas.

4. The image of any external object, the features of a friend, for example, being impressed on the retina of the eye, the individual, judging from the analogy of previous occurrences, feels assured that that friend stands before him, without going through the mental process of tracing the rays of light, which form the image, to the features of that friend, as a source. It is merely the process of association by which one idea or image calls up another. The individual was, in the first instance, taught that a certain visual sensation was connected with a certain friend; whenever afterwards, therefore, that same sensation is experienced, or that same image formed, he infers that the friend is actually before him. It is this principle of association, which furnishes us with by far the larger share of our knowledge; and that this mode of acquiring knowledge is sufficient for mere animal existence, is fully proved by the actions and apparent motives of the lower animals. They have implanted in them from birth, those instincts which urge them to preserve their existence; but, besides these, whatever other feelings they may possess, approaching more or less to the human standard, seem to be derived wholly from association. The dog feels pleasure in seeing his master, because he expects to receive food and attention from him; and the reason for such expectation is, that previous experience has associated in his mind, the idea of his master with that of food and kind treatment; and so of most other similar cases. But it is not necessary to seek among the lower animals for proofs of the pervading influence of this process. The uneducated peasantry of almost every country, derive nearly the whole of their knowledge from this source. If rain fall on St. Swithin's day, for a few successive years, it becomes a part of the popular creed that that day and that event are indissolubly connected. If the thermometer sink, the observer immediately pronounces that the weather is colder; but this he does, not because he has discovered why the thermometer should necessarily sink when the weather becomes colder, but because, from previous observation, a low state of the thermometer and a coldness in the weather are associated in his mind, as co-existing occurrences.

5. Man however is gifted by the Creator with powers of a higher order, requiring education for their developement; but, when once brought into action, amply repaying the labour of cultivation. By the impulse of these powers, man is prompted to inquire why, or through what process, an image is formed on the retina, when an object is presented to the eye: why the thermometer sinks when we feel the atmosphere become colder: why a sound, heard from a certain distance, is less energetic than if heard more near to us: and a long list of similar inquiries, the solution of which is the peculiar office of science. In short, man, in his proper sphere as a reflecting being, should not be content with the mere facts afforded by the evidence of the external senses: if one event, or one state of things, be constantly followed, preceded, or accompanied by another, he should not rest satisfied with anticipating that, when one event should hereafter occur, the other would likewise necessarily accompany or follow it. The admiration with which the works of creation are regarded by every consistent mind, is vastly increased, when the reasons why one set of phenomena occasions other sets, are developed by mental inquiry.

6. Man, then, is by nature an inquiring being. The natural phenomena which occur on the earth, or in the heavens, afford fascinating and sublime subjects for meditation: he studies these phenomena, and classifies them; seeks for common properties; and deduces general truths. Sometimes he directs his contemplation to the heavens, and sees

> . . . . the book of God before him set
> Wherein to read his wondrous works, and learn
> His seasons, hours, or days, or months, or years.

Sometimes he fixes his attention, as it were, to a point, and studies the properties and appearances of a single material substance. But in reflecting upon the vast stores of nature, and in generalizing the results of his reflections and observations, he may be apt to exceed the limits of demonstration: and in passing from observed effects to their causes, uncertainty may often mark his course. Then it is that the judgment is likely to err: but here the true philosopher puts forth real power, and the mere collector of unsystematized facts displays all his weak-

ness—the one slowly raises up an imperishable theory—the other a vague and uncertain hypothesis. Bold and hazardous speculation, unaided by the illuminating power of irresistible analogy, forms no part of the domain of physical science. Where all analogy ends, metaphysics begin: but the mind disciplined by exact science, which requires that demonstration should follow assertion,—which admits the laws of nature when experiment is not wanting to establish them,—and which views with impatience the exercise of mere imagination when applied to the elucidation of external phenomena,—is content with the study of so much of Nature's code as the accumulated wisdom of ages has enabled us to interpret. From this he appreciates the immensity, the infinity with which the Almighty power overshadows his present state of progress and trial, not only as referring to the study and to the use of the productions of Nature, but as comparing his condition here with the prospects offered to him in another and far higher stage of existence, secured to him if he believes and rests upon "the record that God gave of his Son."

7. The curiosity of man prompts him to theorize,—to deal in speculative inquiry. His mind is not content with the view of objects under his immediate ken: he passes in imagination beyond the earth which he inhabits, and views the blue vault of heaven, and finds other worlds, the size and nature of which he ascertains, and combines the whole into a system of which this earth forms but a small part. Distance does not impede him: he measures it. Depth and solidity do not deter him: he penetrates both. Were the firmament formed of solid crystal, he would still be desirous of determining its structure, and of knowing whether any and what objects were situated beyond it. These are but a few of the instances of the bias of the human mind: a bias which leads to good or evil, according as it is exercised. If a man so proudly estimate his mental powers, as to believe that he can unveil all the mysteries around him, and reason on them as if they were the productions of a fellow-man, then will his natural curiosity be an evil to himself and to the world. "Let him that thinketh he standeth take heed lest he fall," is the apostle's admonition, needful to curb

scientific, as well as religious pride. "Not to think of himself more highly than he ought to think, but to think soberly," would make him feel his own weakness without Divine grace in attempting a research into Nature, which God permits him to make for a brief time, and see his own solitude in neglecting the summons to "set his affections on things above, not on things of the earth." But yet if he study the wonderful phenomena presented to him here with an humble conviction of his own unworthiness, and the omnigenous power of the One Great Being who surpasses our conception, he will find this healthy curiosity amply repaid by the acquisition of knowledge which will at once ennoble and elevate him as a thinking being, and teach him to "look through Nature up to Nature's God."

8. In treating of physical phenomena the term *Nature* is frequently employed, and this term requires some explanation. We employ the word in order to express concisely, the *results* of those laws to which the Almighty Creator has subjected the universe; or the *collection* of beings and objects which He has created. Nature, contemplated thus, excites sentiments of respect and admiration at the sight of so many miracles, which may be termed the miracles of natural religion, which come under our observation at every waking hour of our existence; stamped, as they are, with the visible signs of infinite wisdom and power. The mutual connexion which exists between effects and their causes; the concurrence of all the particulars to the harmony of the whole, are a direct proof of the position that the Almighty has made nothing in vain. We know that the Being which constructed the eye must have had a perfect intelligence of light; that He who modelled the ear, must have adjusted it, in an exquisite manner, as well as the medium in which it is placed, through all the fluctuations of such medium, in harmony with the appreciation of sounds.

9. It is not the business of science to dispute with Nature, but to understand her; to investigate the properties of matter, the changes which it undergoes, the modes of its behaviour under various circumstances, its combinations, and its means of application. When a work of art is presented to us, which displays an intricate and curious amount of mechanical skill,

and we witness its operation in the production of certain results, we may fairly and without presumption, question whether the same results be not attainable by simpler means, and with less intricacy; or by a more perfect adaptation of the mechanical powers; since we know the whole design of the artist, and witness all the results which his machine is intended to produce. But when we view a work of Nature, who shall presume to question the perfect adaptation of means to an end? Who will dare to suggest an improvement in a part whose office is known, or venture to doubt the utility of a structure of whose peculiar function we are ignorant?

> Let no presuming impious railer tax
> Creative wisdom, as if aught was formed
> In vain, or not for admirable ends.
> Shall little haughty Ignorance pronounce
> His works unwise, of which the smallest part
> Exceeds the narrow vision of her mind?

The means, furnished to many of the lower animals, are such as enable them to produce results which in elegance, fitness, and minuteness, far surpass the most refined productions of man; and yet we admire, approve, and even copy these results, although produced by "the beasts which perish." Shall we then in the exercise of the distinctive power of reason question the adaptations of Nature? (8.) Shall we venture to place that which we call our own wisdom, in opposition to that wisdom which comprehends worlds within worlds, and systems within systems; from the contemplation of which the mind turns bewildered and confused? No! it is our duty to examine Nature with that humility which true science, combined with religion, induces: feeling assured that, although there is much incomprehensible at present; though there are many phenomena which we may see, feel, hear,—do all, in short, but understand, —yet that the very circumstance of their existence in the scale of animate and inanimate nature, is a sufficient guarantee to us of their utility. This consideration ought to stimulate us to extend the bounds of inquiry, and to seek for the application of fresh analogies; that we may arrive at new laws, by which last term we mean, such laws as we have hitherto failed to discover, or to interpret; for we must be careful to refer the novelty, not

to Nature, but to ourselves, since we are bound to believe that every occurrence in nature is referable to a law which has existed at least as long as man himself; and that this law has ever been irrefragable, except when some wise and benevolent purpose of the Almighty has demanded its suspension.

10. Science does not require that our knowledge should be perfect; only that it should, as far as it goes, be accurate. It is a vain and futile objection, but one that is often urged, that science teaches us so little. It is true that we study the laws of optics, but know not the nature of light: we feel that we live, think, and perceive, but we know not what constitutes life, thought, and perception. The student in science is frequently presented with certain barriers, beyond which he may not pass; with certain limits to the inquiring powers of his mind when subjects such as these are presented to him, whose causes admit neither of demonstration, nor of analogical inference, and are therefore beyond the purposes of physical inquiry. Let him not, then, deal in vague conjecture, which however ingenious, must still be unprofitable; but rather let him turn to the immense field which has been already cultivated so successfully; from whence rich harvests have been gathered, which are treasured up in storehouses, open to the most insatiate appetite. We cannot join in the utterance of the querulous opinion, which, because there is so very much that is unknown, denies the existence of any knowledge at all; for we can assure the reader that the arena of modern science is so extensive, that a very long life of untiring industry would be inadequate to a full investigation of its contents.

11. When we have discovered a law of Nature, it is a sign to us that such is really the case, if it embrace in one harmonious series, certain existing phenomena before known, and claim some others yet to be observed. But when philosophers disagree, the law upon which they differ is imperfectly explained, or not understood; and we may then be quite sure, that that which we pretend is the law of Nature, is only the law of Man. The laws in her code are harmonious in their operation, and consistent with one another; whereas human laws may be created, modified, and changed to suit new emergencies; they

may excite strife and dissension among men, and may admit of a large variety of interpretations. These, then, are proofs, if proofs be wanting, of the imperfection of human institutions when compared with those of the Almighty.

12. How sublime is the reflection that man, whether considered abstractedly, or in relation to the Universe,—so small, so weak, and insignificant,—should, when armed with the giant power of knowledge, be permitted to grasp within his comprehension the wondrous fabric upon which he stands, to soar upwards to other worlds, and to trace out amidst a seemingly unordered maze, beauty and regularity the most perfect!—that the conviction should be carried to his own mind that the Almighty Power has permitted him to understand, although only in part, the plan by which "we live, and move, and have our being." Thus there is afforded us increased means of offering up an humble tribute of praise and thankfulness by combining the observations of natural, with the more precious gifts of revealed religion. Therefore,

> . . . . let zealous praise ascend,
> And hymns of holy wonder to that Power,
> Whose wisdom shines as lively in our minds,
> As on our smiling eyes his servant-sun.

13. Furnished, then, as we are, with means to discover and to understand the laws of the natural world, we see that these present another important distinction from the operation of human laws:—the latter are often mis-applied, or evaded; whereas the Almighty has so constituted the former, that they are self-acting; that is, they bear within themselves the means for inflicting their own penalties. When, for example, we exceed the use of any faculty, the abuse begins; and then also commences the penalties attached to the natural law, which regulates the use of the faculty. Pain is the most apparent symptom of abuse, and usually accompanies it; but the most awful, because mysterious, operation of the penalty, is the premature, but slow, loss of the faculty, either in part or altogether; —the faculty then ceases to act, and its possessor, because he has abused one of Nature's gifts, is deprived of it.

14. And herein there is no court of appeal. It is useless to

urge ignorance of the powers of the faculty, since Nature began by inflicting her penalty by slow degrees; either by imparting to the possessor small increments of pain, or partial deprivation of the power of the faculty; so as to urge, as it were, upon the owner, in her own gentle manner, the necessity of complying with those laws which never vary:—thus chiding him for being so hard a task-master as to exact from a faithful servant more than it was ever calculated to supply.

15. The perfect action of all the faculties, both mental and physical, can only be assured and perpetuated by allowing them certain periodical intervals of perfect repose. The reader may probably assent to this proposition at once, and say that it requires no argument in support of so obvious a principle. But we must remind him that a principle is as important in its nature, as it is unbounded in its application:—that it is the province of science not only to discover principles, but to trace them to effects where their presence is, perhaps, in no way suspected:—that we often recognise the action of a principle in a few effects to which we are most obviously exposed; but that we are often slow to recognise the same principle in effects which afford us a larger amount of pleasure on the one hand than of pain on the other,—which minister to our cupidity, our pride, our vanity, or which flatter one of those "sins which do most easily beset us." Indeed, we cannot often, from ignorance of the extent of a principle, apply it as a cause to effects which we often think have no cause at all, or at least a very remote one; and which, if discovered, we pronounce to be irremediable! But this sort of argument is unjust and unreasonable. In nature there are only a few principles: some of these we think we know: to all of them, whether known or undiscovered, we are subject. Our business, therefore, is to study the code of laws by which we are governed,—to conform with the strictest obedience, since rebellion meets with certain punishment, which, if ever it can be removed, is removed only by a return to obedience.

16. The senses, then, require perfect repose, in order to their perfect action; and this repose implies a removal of any and every cause which excites them to action. By the perfect

action of an organic faculty we mean its legitimate use and employment. The snuff-taker abuses his organ of smell, and its function becomes manifestly impaired. The manufacturer of perfumes is a bad judge of odours from the same cause. The sense of hearing may be also abused. The man accustomed to the din of noisy factories, loses the power of discriminating delicate and minute varieties of tone. Blacksmiths hear soft tones with difficulty; and examples have been abundant of old artillery-men, who have become quite deaf from the long practice of their vocation. The sense of touch is less perfect in the ploughman than in the watch-maker; and most perfect, perhaps, in the blind man, who, by its means, supplies in great measure the loss of sight. Taste also may be abused. The excited reveller scarcely distinguishes the flavour of his "liquid fire" when the banquet has far advanced; and the pampered epicure is gratified only by allowing to his palate intervals of repose. The eye exhibits this principle in a beautiful manner: in its healthy state, its function is being constantly intermitted in the process of blinking, as also by our moving it about towards different objects; but if the eye be kept open and rigidly fixed upon one object, its visual power rapidly declines.

17. Such, then, is an imperfect view of the means with which Nature has furnished us, in order to contemplate and understand her works—a noble and exalting study, when we can remove it from the petty passions and dissensions of mankind—when we can so far purify the mind of its base alloys as to be able to present an offering of virgin gold at the shrine of Nature: and it is the task of her students to do this, of those

> . . . . whom wisdom and whom nature charm
> To steal themselves from the degenerate crowd,
> And soar above this little scene of things:
> To tread low-thoughted vice beneath their feet;
> To soothe the throbbing passions into peace;
> And woo lone Quiet in her silent walks.

18. In the following pages we have frequently insisted on the great importance of scientific principles, in contradistinction to scientific facts. The student must remember that an important process in the inductive system of philosophy is *general-*

ization; whereby a large amount of phenomena is included in one general law, which applies to all the facts supporting it, and which it seeks to explain. A due knowledge and appreciation of these laws is necessary to the successful pursuit of science:—he whose mind is crowded with a large number of facts, unconnected by principles, finds that his progress in knowledge becomes more and more difficult. He must in such case have a distinct memory for every individual fact that he acquires; and in proportion as facts are multiplied, previously acquired facts escape his memory; and his progress one way is continually slackened by his loss in another. But when the student has collected, and tested by an unerring course of experimental inquiry, a large class of facts, and by generalizing them has arrived at a law, which binds them into one harmonious whole, he needs no longer burden his memory with the facts. These may be dismissed from the storehouse of his mind, and laid by in the receptacle of written record, whence they may be reclaimed; and, provided he remember the law in all its extensive bearings, he will have no difficulty in applying it to previously ascertained facts, or to new facts which may arise to his notice.

19. The student must carefully bear in mind that when we speak of a principle or law of nature, it is not implied that such law assigns a *first* cause to the various phenomena connected with it. Its operation is to connect and classify facts, and enable us to say that such a class of phenomena behaves in such a way; and another class of phenomena in such another way. What we call causes are in most cases only removed effects; that is, we explain one effect, by another a little more remote; and then the latter is termed *a principle;* and fairly so, since science does not pretend to the knowledge of *first* causes, but to lead the mind, by slow steps, gradually nearer to the only First Great Cause of all created nature.

20. The study of Natural Phenomena admits of many divisions and subdivisions, which however are not recognised by Nature; but have been formed by man for the convenience of study and for the sake of arrangement. But the numerous

branches of science may all be comprehended in three grand divisions, to which are attached the names of PHYSICS, CHEMISTRY, and NATURAL HISTORY.

21. All the phenomena in Nature in which there is any change of place concerned, in contradistinction to change of composition, are subject to the laws of Physics. If the changes be slight and transitory, so that, when the causes which produced them are removed, the bodies return to their former state, and behave as if those causes had not operated at all; and if the forces, which determine the reciprocal action of bodies, be propagated at distances more or less considerable, we are still in the domain of *Physics*, or *Natural Philosophy*. But, when the reciprocal action of bodies is observed only at infinitely small distances, and the result of this action is the union of the particles of two different bodies, whereby another body is formed, possessing properties peculiarly its own, then the study of this change belongs to *Chemistry*. Again, if the philosopher direct his attention to those beings, some of which enjoy life, and the power of spontaneous motion; others life only; and others a structure, without organization; and if the object be to classify and describe such beings, we include in such a plan the whole of *Natural History*, which is subdivided into three great classes, viz., *Zoology*, *Botany*, and *Mineralogy*.

22. All those substances which are appreciable by the senses, or which the mind can conceive, are included under the general term *matter;* to which two properties are universally attached, viz., *extension* and *impenetrability*. By extension, is meant the property which every body has to occupy a certain amount of space and to possess length, breadth, and thickness. By impenetrability, we mean, that no two substances can occupy the same space at the same time.

23. Matter is also said to be *inert*, because it is passive, and can be set in motion, and when in motion can be brought to rest only by an external force. Without this beautiful property the order and stability of the universe could no longer be maintained.

24. Matter is extremely *divisible;* but it is not supposed to be infinitely so. It has been thought that the ultimate par-

ticles of matter are incompressible and impenetrable; and not susceptible of further division. Hence they are called *atoms;* from the Greek, signifying *not to be cut.*

25. Atoms of matter exert a mutual attraction and repulsion according to the quantity of heat among them; which, in all cases, is supposed to prevent actual contact between these atoms: the spaces or intervals between the atoms are called *pores;* and the porosity of a substance is great when the atoms are furthest apart; and dense in proportion to their proximity to each other. Hence matter is susceptible of *compression* into a smaller bulk, but within certain limits.

26. Matter is *indestructible:* that is, it can never, according to the present constitution of the world, cease to exist. When matter appears to be destroyed it has only assumed a new and often invisible form, or entered into new combinations.

27. Matter of every kind in this world is subject to an attraction towards the centre of the earth by a power which is called *gravity. Weight* is nothing more than the exertion of this attractive force.

28. There are other properties common to certain kinds of matter, which are called *Secondary* properties; such as *hardness*, *softness*, *elasticity*, *density*, *solidity*, *fluidity*, *opacity*, *transparency*, *colour*, and many others.

29. We see then that matter is formed of atoms, which, *cohering* by mutual attraction, form masses; which may be *solid*, *liquid*, or *aëriform*, according to the action of two forces; that of *cohesion* which tends to unite them, and that of *heat* which tends to separate them.

30. Let us now ascertain the modes of observation adopted by the chemist and the natural philosopher in inquiring into the properties of any given substance; such, for example, as the atmospheric air. The chemist does not disregard the essentially physical properties of the air to be examined; he admits them at once, by virtue of his previously acquired knowledge of natural philosophy, which is a necessary preliminary to the exercise of his more peculiar department of science. He then inquires whether the air be a simple or a compound body. Now it is necessary to inform the reader before we proceed, that the

chemist refers matter of every kind to a list of substances, fifty-four in number, which are called *Elements.* Thus, iron is a simple substance or element; which has never been resolved into other parts than iron: however much it may be reduced in size, it is still iron. So that, from a simple substance, only one kind of matter can be taken, which is identical with that substance. When two or more simple substances unite, a compound body is formed; and indeed nearly all the substances with which we are presented by Nature, are compounds, resolvable into one or more of the fifty-four simple bodies. Thus, chalk is a compound, for it may be resolved into carbonic acid and lime; and these two bodies again are compounds, for the former may be resolved into carbon and oxygen; and the latter into the metal calcium and oxygen: so that chalk is a compound body from which three kinds of matter may be obtained, viz., the simple substances, oxygen, carbon, and calcium. When a compound body is resolved into its elements it is said to be *decomposed;* and the chemist would find that the atmospheric air is a compound body capable of supporting animal and vegetable life, and combustion. But if he immerse an animal or a lighted paper in a confined portion of the air, he finds that the animal soon dies and that the flame is soon extinguished; also that the air is diminished in bulk. Hence he derives the very reasonable inference that the air contained some body, or principle, which enabled the animal to live, and the light to burn; for if another animal and another light be immersed in the residual air, both the life and the flame would be immediately extinguished. If now the chemist take a certain compound substance known by the name of the sesqui-oxide of lead, commonly called red-lead or minium; or a substance called the per-oxide of mercury; or another called the black oxide of manganese, and heat any one in a close vessel, an air will be given off, which when collected, will be found to possess properties similar to those of the atmosphere, but more energetic in character. An animal will live in a confined portion of it for a much longer time than in common air; and a flame will burn in it far more brilliantly. Nay, more, if one portion of this air be added to four portions of the air which

was vitiated by the respiration of the animal, and by the combustion of the flame, the resulting compound will exhibit all the properties of common atmospheric air.

31. Now, as the properties of bodies are not of a fitful and uncertain character, but behave precisely alike under like circumstances at all times, the chemist is justified in the inference that bodies always acting thus precisely alike under all circumstances, neither more nor less, are identical. Now, when by taking five parts of air and getting rid of one part, we find the resulting four parts to possess properties of a negative kind; refusing to support life and combustion, and exerting no other chemical action whatever; and when by distilling a peculiar kind of air from certain mineral bodies, which air is as positive in its action as the other was negative; and when, moreover, we find that by adding one part of this air to four parts of the negative air, we get a compound, bearing the identical properties of the atmosphere, the inference is that the one part which disappeared from the five parts of air is the same aërial substance which exists in a solid state in the red-lead, in the oxide of mercury, and in the oxide of manganese.

32. Pursuing his inquiries in this way, the chemist finds that air must be referred to that class of bodies, which are called compound: that the air is composed of two simple gaseous substances, the one called *Oxygen*, and the other *Nitrogen;* whose properties are of an opposite kind: that these bodies unite in the proportion of one part of oxygen to four parts of nitrogen. He finds, moreover, that these airs, or, as they are called, *gases*, exist in a state of mere mechanical mixture; for he can form the air we breathe by merely mingling the two, since they do not form that intimate union which marks the combination of most other compounds, such, for example, as of the oxygen and lead; or of the oxygen and mercury and manganese, which compounds require a high degree of heat to effect decomposition. He finds also that oxygen combines abundantly with the metals, forming oxides; and that these oxides are soluble in acids and form salts; that nitrogen is, from its inert character, mingled with the oxygen in the atmosphere apparently for the purpose of dilution; in order to prevent the

active qualities of the oxygen from being exerted with such vigour as to prove pernicious.

33. Let us now suppose that the natural philosopher is furnished with a given volume of atmospheric air; and that he is required to investigate its properties according to the means which physical science affords. He will find it to be material, invisible, inodorous, and insipid. Supposing the air to be contained in an elastic vessel, he will find that expansion by heat, and contraction by cold, or by pressure, are properties common to it; therefore he calls it an *elastic aëriform* body. On continuing to apply pressure and cold to it, he will be unable to alter its state,—that is, it continues to be an air, and does not possess the property common to vapours, and some gases, of being reduced to a liquid or a solid state by cold and pressure, one or both; therefore, he calls air a *permanently* elastic fluid; he calls it a *fluid*, because the particles which compose it move about among each other without the retarding agency of friction. By enclosing and suspending a given quantity of air in a delicately constructed balance, he will find that it possesses weight, for the vessel containing the air will weigh less if it be exhausted by means of an air-pump; and as a consequence of weight, that the air exerts a pressure upon all bodies exposed to its action: that it is impenetrable, because it fills a space. Extending his inquiries from the small bulk of air which is immediately under his examination, to the mass of air which surrounds the globe, he will trace a limit to its existence, calculable by the ratio of its decreasing density in proportion as he ascends from the earth; he will mark the boundary where the air ends, and space begins. He will prove that on the air depend many of the most necessary and useful functions of our life. As the chemist proved that this fluid is necessary to life and combustion, so will the natural philosopher prove that sound is a necessary consequence of aërial pulsations; that heat, light, and electricity pervade it, performing thereby thousands of beneficial operations in the three kingdoms of Nature. He will observe that the great aërial ocean is subject to perpetual changes, and will contrive instruments for noting its fluctuations:—he will connect the phenomena of mist, dew, rain,

hail, snow, wind, storm, and tempest, with the wonderful object of his inquiry. His domain will seem illimitable; for wherever he may extend his inquiry over all created nature, he will find that the agency of the air is kept up in the sublimest as well as the minutest objects of his research. Without the air, the heavenly bodies could not be seen; without the air, the animalcule, whose ocean is a drop of water, could never have been detected; without the air the human eye and ear would have been formed in vain, and this beautiful world would degenerate into a second chaos "without form, and void," and darkness would again be upon the face of the deep. The natural philosopher will also make the arts of life the object of his examination; whether he marks the ship wafted over the sea by the gales, or traces the mighty operation of the steam-engine, which defies both wind and tide. He will show how the water rises in our pumps; how men soar aloft above the clouds in the balloon, or seek the treasures of the deep in the diving-bell. He will explain how the fly walks on the ceiling, and apparently opposes gravity; and how the fish buoys itself up by a beautifully adjusting air-vessel. These are a few of the subjects which make the natural philosopher acquainted with the aspect of nature in all her moods from loveliness to sublimity; a mighty task! which without intruding into the domain of the chemist may worthily engage him for his life-time, in active employment, useful alike to himself, and to his fellow-creatures.

34. Admirable and extensive as is the department of the chemist, that of the natural philosopher is not less so. The chemical and the physical properties of matter are separated; not because such a separation is natural, but because it is convenient for the purposes of study and arrangement; and more than this, because the human mind is seldom of such capacity as to embrace an intimate knowledge of both these departments of science.

35. The following treatises are intended to place before the student in a lucid manner, some of the physical phenomena of nature. We are about to describe the working-tools of the philosopher, which the young apprentice in science will have

to employ hereafter. It is important to remark that the instruments employed by the philosopher are, to a great extent, only imitations, in miniature, of the processes which Nature herself employs in her operations. It becomes, therefore, an instructive inquiry to ascertain the principles upon which the action of such instruments depends, and the methods of using them.

36. We proceed, therefore, to explain the purposes of the present work, and the means which the student should adopt in order to peruse its contents with greatest advantage to himself.

37. It is obvious that the study of experimental science requires either that the experiments should be repeated by the student, or that he should receive them from such an authority, and in so lucid a manner, as that their accuracy may be placed beyond a doubt, and their due comprehension rendered easy. But the latter point is not always effected by reading only, whatever may be the merits of the writer. The student must himself perform experiments; and in order to do this, apparatus is necessary, which is generally costly and therefore beyond the reach of the many. But, by the exercise of a little ingenuity, and at a very moderate outlay, apparatus may be constructed which will be adequate to the performance of a great number of leading experiments. We will detail the apparatus necessary for the due comprehension of the subjects of the following pages, in the order of their course.

i. Provide a small tube, with a bulb at one end and open at the other. If the open end be inserted into a bottle containing spirits of wine, and a flame applied to the bulb, the heated air will expand, and a part of it will escape through the liquid, in proportion to the heating effect. If the bulb be allowed to cool, the spirit will gradually ascend in the stem, and thus an air-thermometer will be formed. If, again, the spirit be made to fill the bulb, so that at the ordinary temperature it may also occupy a portion of the stem, and the bulb be placed in hot water, the spirit will ascend the tube, thus showing the action of the common thermometer.

ii. A tube about thirty-two inches in length, closed at one end, and a pound or two of mercury. If the tube be filled with mer-

cury, and inverted in a small cup of the same fluid, the student will see the formation and action of the barometer.

iii. An empty egg-shell, with a reed of straw inserted at the small end and secured by sealing wax: also another reed of straw at the large end, similarly inserted, to which is affixed a piece of lead:—this will furnish a very good hydrometer; which will be found to stand at different depths in liquids of different densities, such, for example, as water, milk, beer, spirits, &c. The upper straw may be graduated roughly by placing the instrument in water at the ordinary temperature, or still more accurately, in pure water at 60°. An inch below the water-mark, and two inches above, may be graduated into tenths of an inch by drawing ink-lines, or by scratching the straw.

iv. The action of the hygrometer may be shown by bringing a glass of cold spring-water into a warm room. Thus, with the aid of a thermometer, the dew-point, and other important circumstances attending the action of this instrument, may be noted.

v. A few pieces of card, carefully graduated by the student, will be quite sufficient to explain the action of the vernier.

vi. A small horse-shoe magnet may be purchased for a shilling. This will be quite sufficient to communicate temporary magnetism to pieces of soft iron wire, and permanent magnetism to sewing or darning needles. If one of these needles be thrust through a piece of cork, just sufficient to buoy it up on water, the various phenomena of direction, attraction, repulsion, and dip, may be illustrated by acting upon the floating needle with the horse-shoe magnet, or by means of another magnetised needle held in the hand. The needle may also be suspended at its centre by a piece of thread. If the horse-shoe magnet, without its armature, be placed on a table, and be covered with a piece of writing-paper, and a few iron filings be sifted upon it, the magnetic currents will be exhibited.

vii. The student will require a tuning-fork, and a few wafers or discs of card; also a tube of glass open at both ends, and a cork accurately fitted into the tube. The cork must be stuck upon a piece of wood or wire, so as to be moved up and down in the tube. A few drops of oil spread over the cork will facilitate

its motion. Thus the experiments on the reinforcement of sound can be verified.

viii. A glass goblet and a violin-bow, together with some thin wire; also water coloured with ink,—a conical glass, and a small quantity of lycopodium, will enable the student to verify nearly all the experiments with glass vessels. He may also construct for himself a set of musical glasses, at a very moderate cost.

ix. A prism of flint-glass will be required mounted upon a wooden stand; the two ends of the prism must be fixed into moveable sockets, so that the instrument may be turned round as occasion requires. The student will construct plane, convex, and concave mirrors according to the directions given in the article on the Prism. The effects of a globe of water on light may be shown by employing the bulb mentioned in No. i., and the flame of a small taper.

x. The construction of the refracting telescope may be understood by expending a few shillings in the purchase of a common opera-glass. By unscrewing the joints, the lenses may be inspected, and their foci examined. The action of the reflecting telescope may be seen by reference to the concave mirror mentioned in the Prism.

xi. The student will of course form a bottle of soapy water according to the directions given in the article on the Soap Bubble. He will also make use of his prism to illuminate the film with the variously coloured rays in succession. If he purchase small portions of nitrate of barytes and muriate of strontian, and dissolve these, as also some common salt, in spirits of wine contained in little dishes, he can examine the film by means of green, red, and yellow flames. Boracic acid and nitrate of copper similarly dissolved will furnish pale and dark green flames.

xii. The student will do well to construct sun-dials from pieces of card-board: for the style he may employ a stout pin or wire. He will, of course, verify the experiments on the flow of water and of sand. If he procure a glass cylindrical vessel, he can easily bore a hole through the centre of its bottom, by means of a common awl, kept moist with turpentine.

38. We cannot close this introduction without an earnest hope that the young student will perform the whole of the experiments as above directed. He will thus find the study of the following pages much facilitated; and at the same time will acquire, in some degree, the art of manipulation. There are many other experiments to be found in the course of this volume, which he can easily verify, and therefore we have not set them down in the directions above. Of course, in every case, the extent of the student's apparatus must be regulated by his means; but, we would suggest, that, whatever be his means, let him cultivate early the habit of depending chiefly upon himself for his apparatus; for we have found, from long experience, that no experiments are so satisfactory, or so pleasing, as those devised by the student himself, or performed with apparatus constructed by his own hands.

C. T.

Salisbury, 1838.

I.

THE THERMOMETER.

First Heat from chemic dissolution springs,
And gives to matter its eccentric wings;
With strong Repulsion parts the exploding mass,
Melts into lymph, or kindles into gas.—DARWIN.

1. IN our present position on the globe, we are indebted, under Providence, to heat for most of our comforts and enjoyments. Nay, our very being, our physical existence, depends upon the presence of this wonderful and powerful agent of nature. Our frame is admirably adapted to the clime that we inhabit, and the varying changes of heat, which constitute all the vicissitudes of climate and seasons, we are calculated either to withstand or to enjoy. Heat is the sole cause which sets in motion a thousand sources of exuberance and fertility, producing an universal burst of joy and gladness at the approach of the new-born spring;—which clothes the earth in its beautifully variegated summer-robe;—and which prepares the riches of autumn to fill the store-houses of living creatures, thus providing for that season, when, by a diminution of heat, the earth and the waters are bound up in ice and snow; when the vegetable world is leafless, and fixed in the torpor of apparent death; until heat again becomes present to us in more abundant quantities, (for we must not suppose that heat is entirely absent even from the coldest bodies,) and spring comes round again. Thus the seasons return with the year, the duration of each being modified by the particular position we may refer to on the surface of the globe.

These, as they change, Almighty Father, these
Are but the varied God. The rolling year
Is full of Thee.

2. Heat is every where present: it is within us, and around us; it produces the immense varieties of the animal, the vegetable, and the mineral world. The very air we breathe owes its form and elasticity to heat. Water we know may be a solid, a liquid, or an air, according as heat is distributed in

it. By means of heat we get our implements of art, science, or domestic life. Without the artificial aid of heat, our food would be insipid, and often destitute of nourishment. In short, all the offices and contrivances of man, of the other animals and of vegetables, are made with especial reference to this all pervading principle; and yet science, which never blushes to own her ignorance, knows absolutely nothing of heat, except by its effects. The cause of heat is unknown; but its effects are most abundant, and these have been collected and generalized with so much industry and scientific skill as to form a distinct science, the study of which is not only useful, but indispensable to any one who desires to investigate the beautiful phenomena of the material world.

3. We are about to present the reader with a concise account of the Phenomena of Heat, so far as is necessary to the due appreciation of the modes of constructing and applying thermometrical instruments. The Thermometer is one of those instruments the use of which is almost universal. The simplicity of its make, and the ease with which it is observed, have generally led to a disregard of the principles upon which its action depends; and the degree of reliance placed upon it must, therefore, in such a case be entire. But this is wrong. All our instruments are more or less imperfect in their action, and their indications require correction by a knowledge of their principles. In proportion to the absence of this kind of knowledge, the senses will be taken as guides, without being submitted to the correcting influence of reason, and of judgment, fortified and improved, as these ought to be, by education and study. The possession of a musical instrument avails but little, if the skill to play upon it be wanting: and, in like manner, the possession of a scientific instrument, without the skill to test its action by reference to scientific principles, avails scarcely more. A person may be very busy about science, without being scientific. We mean, that he may possess the knowledge of a large number of facts which each experiment is meant to prove; but, unless these facts be connected by principles, founded on a train of reasoning well understood, they have a separate existence in his mind; they belong to memory alone; whereas, principles belong, not to memory, but to the reasoning powers, which receive facts and phenomena, and reduce them to laws; and these laws are always ready to explain crowds of facts, with which the mind need not be burdened. They may be stored up in books, since the memory cannot retain them all; and it is

enough if the student know how to generalize them, or to understand and interpret the generalization of others: he will never be at a loss to explain ordinary facts, for like an accomplished legal judge, who possesses a knowledge of laws, which he has applied to thousands of cases, without being careful to remember individual cases, the student of nature may apply the laws of science to thousands of facts of frequent occurrence, and which, in like manner, he need not care to remember.

Section I. On Heat.

4. In science, heat is considered to be an effect, whose cause, whatever it may be, is known by the term *caloric*, or the *principle of heat.* The term heat, therefore, implies a sensation of which caloric is the cause.

5. What may be the nature of heat, is a matter of pure conjecture only. It has been supposed to consist of matter of extreme tenuity, so much so, that our most delicately constructed balances are unable to detect a change of weight in a body either by the addition or abstraction of heat. The particles of this fluid, (as heat is termed,) are supposed to be endued with indefinite self-repulsive powers; that is, its particles naturally repel each other; and this is proved by the fact that heat flies off from a heated body, and is attracted and retained by other bodies, whose particles it pervades.

6. Others, again, deny the separate existence of a calorific principle, and suppose that a vibration, or intestine motion, of the particles of matter is the cause of heat. Numerous striking experiments may be adduced in favour of either hypothesis; and there are certain facts which seem to be explained by one theory better than by the other. Into this discussion, however, it is not our business to enter.

7. But whatever may be the cause of heat, the sources whence it is derived are sufficiently obvious. By a source of heat we mean that object or process, either natural or artificial, by which the quantities of heat contained within a body, may be increased, so as to become appreciable to the senses, or to the thermometer. The sources of heat may be considered to be;—1st, The Sun. 2nd, The Electric Fluids. 3rd, Condensation. 4th, Percussion. 5th, Compression. 6th, Friction. 7th, Chemical Action, and 8th, Animal Life. These sources of heat we shall briefly consider in the order above. We shall then treat of some of the most general effects of heat, such as *expan-*

sion, *fluidity*, *ignition*, and *combustion;* as also the subject of *specific* heat. For the subject of *vaporization*, we must refer entirely to our article on the Hygrometer. In the third place we propose to consider the means by which heat is diffused, under the terms *Conduction* and *Radiation.* In the second section we will resume the subject of *expansion*, by describing a variety of ingenious instruments that have been contrived for measuring temperature.

8. *First Source.* THE SUN. We are compelled to admit, by irresistible analogy, that the source of light to the system, of which our globe forms but a small part, is also the source of heat. But heat seems to be excited only when the solar ray is absorbed; since the temperature of transparent bodies through which it passes, or of polished surfaces by which it is reflected, is scarcely changed. The double convex lens and the concave mirror, in whose foci intense heat is developed, are not of themselves hot. The intense coldness, experienced on the tops of high mountains, even within the tropics, arises from the same cause:—the solar rays pass on through the air unabsorbed; and the air at the surface of the earth would probably be unfit for the purposes of life, did it not receive heat by direct communication with such surface. Those bodies, from which heat escapes most readily by radiation, absorb both heat and light in greatest abundance. Their property this way is much influenced by colour. Dr. Franklin placed differently-coloured pieces of cloth, of the same size and texture, upon snow, and allowed the solar rays to fall upon them. The dark coloured pieces absorbed more heat than the light ones; since the snow was melted away in greater quantity from under the former than from under the latter, and it was remarked that the effect was in the ratio of the depth of shade. According to Dr. Stark, the order is as follows: black, brown, green, red, yellow, and white,—each of these absorbing less heat than the colour before it. Hence also our dress in summer and in winter generally varies in colour; since a light dress absorbs less heat than one of a dark coloured material. (83.)

Professor Robison enclosed the bulb of a thermometer in a box with a glass cover, which prevented the cooling influence of the air, and lined the inside of the box with charcoal; a substance which absorbs a large amount of heat. On allowing the solar rays to enter the box, the thermometer rose to 237°. By a similar contrivance Saussure obtained a temperature of 221°. The calorific rays of the solar spectrum will be considered in our article on the Prism.

9. *Second Source.* Electricity. That electricity is a source of heat, as well as of light, must be a familiar fact. Lightning often produces serious accidents by igniting gunpowder and other inflammable bodies; and in general, when electrical equilibrium has been disturbed, its sudden restoration is attended with intense heat and light; so much so, that ether, spirits, resin, gunpowder, &c., become readily ignited. The passage of an electric current between the poles of a galvanic battery is attended with extraordinary heat and light; so that the most refractory bodies, placed in its course, melt down like wax. We are not yet informed of the influence of electricity in the vast economy of nature: it is doubtless very great; but so subtle is its action, that except on the grand occasions of thunder-storms, we are scarcely aware of its presence. Some have gone so far as to identify it with solar light and heat;—but this is an unwarrantable conclusion, in the present state of our knowledge.

10. *Third Source.* Condensation. If we take the familiar example of water in three of its states, we shall find that each state depends upon heat in greater or less proportion—thus: steam at 212° owes its form to its high temperature: if this be diminished, water results: if we continue to abstract heat from it, we get solid ice. So that when steam is condensed into water, it parts with a certain amount of heat, which may be communicated to any other body, and thus become a source of heat.

It is usual in some manufactories to raise a large quantity of cold water to the boiling point in a few minutes by passing steam into it; which being condensed by the cold water, the latter absorbs its heat, and thus soon acquires the temperature of the steam itself.

So also in converting several of the gases into liquids; they are subjected to intense pressure and cold;—the means whereby they exist as airs being removed from them, they become liquid or even solid.

11. The three following sources of heat are mechanical actions, by which a body is reduced in its dimensions; so that its particles become condensed, and its temperature increased.

Fourth Source. Percussion. In the lock of a gun, the flint strikes against the steel, and chips off small particles of the metal, which, by the percussion, becoming red hot, fall into the gunpowder in the pan, and ignite it. This ignition communicating with the gunpowder in the barrel produces the explo-

sion of the whole. In this case the atmospheric air is necessary to support the combustion of the metallic particles; for if the experiment be performed in vacuo, sparks may indeed be seen, but the gunpowder will not be kindled. When a gun is said to "hang fire" none of the red hot particles fall into the powder in the pan.

The blacksmith is in the habit of kindling his fire by hammering a piece of iron until it becomes red hot. After a certain amount of hammering, the metal ceases to evolve more heat, until it has been again made red hot by the fire.

12. *Fifth Source.* COMPRESSION. If we suppose an elastic vessel, of the capacity of 100 cubic inches, to be full of air under a pressure of 30 inches of mercury, at a temperature of 60°, and to be transported to the summit of Mount Chimborazo, the vessel and its contents, being relieved from a large amount of pressure, would expand to a very great extent. This mountain, or at least the most accessible point reached by Humboldt, is 19,332 feet above the level of the sea. The barometer at such an elevation would stand at 14·850 inches, according to Humboldt. The vessel containing 100 cubic inches of air, instead of being subjected to a pressure of $14\frac{1}{2}$ pounds on every square inch of its surface, would then receive only about seven pounds to the square inch, and it would consequently expand to the capacity of about 200 cubic inches; being still full of air, although in a highly rarefied state. If the 100 cubic inches of air at the level of the sea contained a given amount of heat, the 200 cubic inches on the top of the mountain would contain the same amount of heat, but so largely diffused that the almost entire want of concentration would reduce the thermometer below 32°;—and hence it is that the tops of high mountains are covered with perpetual snow.

We see, then, that, as rarefaction produces cold, we may, by an easy analogy, infer that compression produces an opposite effect. If the 100 cubic inches of air were suddenly reduced to 50, a flash of light, and an elevation of temperature, would mark the compression. We should have the same amount of heat, but the air by a sudden decrease of volume would have more heat than would be consistent with its reduced bulk; and the surplus quantity, that is, the amount of heat necessary to preserve 50 cubic inches of air at 60° and under 30 inches pressure of mercury, would be given off.

The fire-syringe is an instrument constructed on this principle. It consists of a brass cylinder closed at one end, and a piston fitting air-tight. The end of the piston is hollowed, to contain a

small piece of *amadou**, or *German tinder*. By suddenly thrusting the piston down the cylinder, the air is compressed within a very narrow compass, and sufficient heat is liberated to ignite the tinder.

13. *Sixth Source.* FRICTION. The Indians procure fire by rubbing two pieces of wood together, and every one must be familiar with numerous facts connected with the evolution of heat by friction. The axle-tree of carriages, when not sufficiently greased, may become red hot, and set fire to the wheel; and the sides of ships have been known to take fire, by the rapid descent of the cable. In the whale-fishery, when a whale is struck by the harpoon, it descends with sudden violence,—drawing with it the harpoon-rope, which passes rapidly over the side of the boat. It is necessary to pour water upon the edge of the boat to prevent it from taking fire. In some factories, where pieces of machinery are in rapid motion, it is necessary to supply the parts most exposed to friction, with a stream of water, to keep them cool. The trick of a school-boy who rubs a flat button against the desk and claps it up to the face of his school-fellow is also referable to this place.

This subject has been investigated experimentally by Count Rumford, who has produced some extraordinary results. By applying great mechanical force to a blunt steel borer, which was made to work at the bottom of a hole in a cannon-like block of metal, the temperature of the latter was raised within half an hour from 60° to 130°; the precaution having been taken to cover the metal with flannel to prevent the escape of heat.

In another experiment, the metal block was enclosed in a wooden box filled with water, the borer being also surrounded with that fluid. The quantity of water amounted to 18·77 pounds avoirdupois, and the initial temperature of the whole was 60°. The cylinder was made to revolve for an hour at the rate of one revolution in two seconds, whereby the temperature of the water was raised to 107°. In another half hour it was raised to 178°. In another hour the water boiled.

If two pieces of ice fastened to the ends of two sticks, be rubbed together in air at a temperature below 32°, they will melt by the friction. Sir H. Davy caused two pieces of ice to melt by rubbing them one against the other in the vacuum of an air-pump, when the temperature of the apparatus and of the surrounding air was below 32°. It has been remarked, that

* A species of fungus—the *Boletus igniarius*. It is prepared by steeping it in a strong solution of nitre and then thoroughly drying it.

when the surface of the rubbing piece was rough, only half as much heat was evolved as when it was smooth. When the pressure of the rubbing piece was increased four times, the proportion of heat evolved was increased seven-fold. When the rubbing piece was surrounded by bad conductors of heat, or by non-conductors of electricity, the quantity of heat evolved was diminished.

No heat whatever can be detected by the friction of fluids upon each other, or upon solids, nor by the friction of gases upon liquids or solids.

In all these cases of the evolution of heat by friction it does not appear that increase of density can be assigned as the cause, since the effect is produced by rubbing soft bodies against each other, such as the hands. Nor does the capacity (68) of the bodies for heat seem to be changed by the frictional action. Again, it is in no way connected with the air or any other supporter of combustion. In short, we cannot explain the action of friction in producing heat, unless we assume it to be the cause of a vibratory action of the particles of matter, which in the hottest bodies move with the greatest velocity, and through the greatest space.

14. *Seventh Source.* Chemical Action. This source of heat, next to the sun, is, perhaps, the most prolific. All the various phenomena attending the combustion of our lamps, our candles, and our fires, belong to this source (58). Chemical science furnishes crowds of illustrative facts. In truth no chemical combination ever occurs without an elevation or depression of temperature. Heat is always evolved when the density of the resulting compound is greater than the mean of the substances which compose it. If sulphuric acid and water be mixed, or alcohol and water, or muriatic acid gas be passed through water, a rise in the temperature is marked and decided; sometimes the increase is more than 150° or 200°. It is well known that water, thrown upon quick lime, produces much heat:—the water is in fact solidified in its union with lime:—a hydrate is formed whose density is far greater than the mean of the two substances in their uncombined state.

The subjects of *ignition* and *combustion* will be considered hereafter (58); and under the term *Fluidity* (34) we shall take notice of other phenomena connected with change of temperature from chemical action.

15. *Eighth Source.* Animal Life. Wonderful and mysterious as much of the mechanism of an animal is, yet the powers by which such animal lives and moves are still more so.

Although we are in ignorance of many of the processes of nature which conduce either to our very existence or to our general well being, yet so soon as we catch but a glimpse of any one of these processes, the educated mind is urged on by the powerful stimulus of laudable curiosity, to inquire into, and develop, the whole process, until it stands before us in all its beauty, and simple grandeur. But such a work as this is necessarily of slow progress. Many years, and the efforts of many great minds, are required to yield sure and certain knowledge. Many are the errors, the crude hypotheses, the doubts, and difficulties, to be removed, the calm investigations to be made, before we are entitled to say that we understand nature. Such difficulty as this belongs to the subject before us; —How does an animal acquire its heat? is a question very difficult to answer satisfactorily. The blood of

> The shudd'ring tenant of the frigid zone,

And of

> The naked negro, panting at the line,

scarcely differ from each other in temperature, although surrounded by such widely dissimilar degrees of heat.

16. It is generally admitted, that respiration is the cause of animal heat. The process of respiration very closely resembles that of ordinary combustion. Dr. Crawford, to whom we are indebted for an admirable theory on animal heat, states that the specific heat of arterial blood is greater than that of venous blood*, in the proportion of 1030 to 892; and that consequently, as the blood passes from the lungs into the arteries, its capacity for heat is suddenly increased, and the heat evolved by the combination of oxygen with carbon in the process of respiration, is consumed in supplying to the arterial blood, that additional quantity of heat which its increased capacity renders necessary for the preservation of its temperature. The arterial blood, in passing through the arteries into the capillaries†, is supposed to undergo a diminished capacity for heat, and heat, therefore, is dismissed into the system. So that the heat absorbed by the arterial blood in the veins is

* The reader may here be informed, that venous blood is that fluid which flows along the veins in its passage to the heart through the lungs, where it is supplied with oxygen, which changes its dark purple colour, into bright scarlet. It is changed, in fact, from venous blood into arterial blood, in which state it passes into the heart, in order to be pumped out into the arteries.

† The capillaries are those minute vessels in which the arteries terminate, and from which the veins are supposed to begin.

communicated to every part of the system, and its temperature preserved.

This theory has been at different times questioned by some physiologists; while others have supported it with slight modifications. It does not belong to us to discuss this question. We may merely remark, that the production of animal heat is now generally admitted to be a chemical operation, which depends upon the combination of oxygen with carbon in the capillary arteries of the animal system; that is to say, it is the result of the combustion of charcoal at every point of the body.

17. With this slight sketch of the sources of heat, we now pass on to notice some of its effects: but before doing so, we will briefly allude to the late Sir J. Leslie's classification of the sources of cold. Cold, we know, is nothing more than a deprivation or diminution of heat; but it is convenient, in common parlance, to speak of sources of cold.

Sir J. Leslie divides such sources into—1st. The obliquity or absence of the sun. 2nd. The tenuity of the higher atmosphere. 3rd. The evaporation which takes place in dry air. 4th. The chilling impression shot downwards from a clear and serene sky. As instances of the operation of the first source of cold, he adduces the frozen Baltic, over which armies have passed; the congelation of wine and spirits, in some parts of Russia and Sweden; the freezing of the sap in the roots of trees, by which they are burst asunder with great force, &c. The second source of cold, he illustrates by reference to the diminished temperature observed at great altitudes, amounting to as much as 68° in ascending $3\frac{1}{2}$ miles. The third source, or that resulting from evaporation, he illustrates by all those contrivances, which, under the name of coolers, diminish the temperature of liquids by evaporation. Galen relates that he witnessed the mode of cooling water, which was practised in his time, not only at Alexandria, but all over Egypt. The water, having been previously boiled, was poured at sunset into shallow pans, which were then carried to the house-tops, and there exposed during the whole night to the wind; and to preserve the cold thus acquired, the pans were removed at daybreak, and placed on the shaded ground, surrounded by leaves of trees, prunings of vines, lettuce, or other slow-conducting substances. The water-bags of the Bedouin Arabs allow a small quantity of water to exude from them, which being evaporated, cools the rest of the contained water. The gourds and calabashes of the Africans,—the alcarazzas of the Moors,—the wetted matting curtains of Oriental nations, &c., are all instances of the operation of the same law.

The fourth source of cold which Sir J. Leslie enumerates, is the impression of cold which is showered down from a serene azure sky. In fine clear climates, a transpiercing cold is felt at night, under the clear and sparkling canopy of heaven; from which cold the natives sedulously shield themselves. The captains of the French galleys in the Mediterranean, used formerly to cool their wines in summer by hanging the flasks all night from the masts; at daybreak they were taken down, and wrapped in several folds of flannel, to preserve them in the same state.

Many of these particulars we shall have to allude to in other parts of this volume; but we wished to give an abstract, in this place, of the mode in which the distinguished Leslie viewed the various sources of cold. We now proceed to the consideration of the effects of Heat, and we begin with the subject of *Expansion*, as the most important in connexion with our subject.

18. By expansion, we mean that repulsion which exists among the integral particles of a body, occasioned by the entrance of heat, whereby such particles are removed to a greater distance from each other. The expansive power of heat is opposed by the cohesive attraction of the particles themselves for each other; and as this attractive force is different in amount in different solids and liquids, so is their expansion and contraction necessarily different for the same changes of temperature. In general, the rate of expansion is in proportion to the density; such bodies as are most dense expanding least; while on the contrary, those bodies whose specific gravity is small, suffer greater expansion, compared with the former; the increments of heat being equal. Density or specific gravity, indicate, in fact, the amount of cohesive attraction, and this we find to be greatest in solids, less in liquids, and least of all in airs; while the expansion by heat is small in solids, is greater in liquids, and greatest in airs. But in every case, the expansion of the same body increases with the amount of heat which enters it.

19. That solids expand by heat, may be proved by measuring exactly the length, breadth, and thickness of a bar of metal, for example, when cold, and again, when heated; it will thus be found to have increased in bulk every way. A very common class experiment is shown by the lecturer to demonstrate this fact. A cylindrical rod of iron furnished with a wooden handle fixed to one end of a wire, the other end being inserted in the middle of the cylinder, is made to fit exactly an iron gauge, corresponding to its length, and a hole made in the

same gauge, corresponding to its diameter. When the cylinder and the plate are at the same temperature, the diameter of the cylinder will exactly fit the hole, and its length will be precisely that of the length of the gauge. If the cylinder be heated in the fire, it will be found that the hole and the gauge are both too small to receive it. But when the cylinder has cooled down to the temperature of the surrounding air, it will fit the gauge and the ring as before. Or if the gauge be heated to the same temperature as the cylinder, the gauge and the ring will respectively correspond to the length and diameter of the latter.

20. We have seen then, in this experiment, that when iron is heated it expands; and that when abandoned to itself, it regains its former dimensions. A curious instance is furnished in the arts, in which it appears that steel heated to a high temperature and suddenly cooled, retains nearly the same bulk which it had under the influence of such high temperature. This process is called *tempering;* by which the hardness, elasticity, and durability of the metal are much improved. It appears, then, that by tempering, steel is held in a forced state of dilation. We will give an example. A cylindrical steel die, such as is used for medals, is made to fit exactly a hollow cylinder of its own diameter. The die is now tempered, and it will be found impossible to make it enter the cylinder. If they be tempered both together, and the substance of the cylinder be such as not to display the usual effects of temper upon steel, so that upon being cooled, it returns to its first dimensions, the die in dilating and remaining permanently dilated, becomes distorted in a manner, as if it had been violently driven into a space much smaller than itself; a ridge of metal is in fact raised around the two circumferences of the die, and it is thus kept fixed within the cylinder with an enormous force. This remarkable fact has been explained by M. Biot thus:—It is supposed, that the instant when the steel, being strongly heated, is suddenly cooled, the cooling effect is first experienced by the exterior layers of the metal, which become moulded as it were, and fixed upon a centre which is still strongly heated and dilated; by this means the die is made to occupy larger dimensions than it would have done if it had been allowed to cool gradually. The molecules near the centre of the mass cool at a later part of the process, but the exterior layers having already acquired a fixed state, retain the interior particles in a state of great expansion, and thus determine the volume which they occupy, and prevent them from approaching so near to each other, as they

would have done had the whole mass been allowed to cool gradually*.

21. If this theory be true, and it has much of the appearance of truth, it is still inadequate to the solution of the very difficult question why a sudden cooling producing such effects on steel, does not also produce analogous effects on gold, tin, copper, and other simple metals.

22. The following table exhibits the rate of elongation of a few interesting substances, when heated from 32° to 212°.

Glass tubes made without lead, a mean of three specimens	$\frac{1}{1113}$ of its length.
English flint glass	$\frac{1}{1248}$
Copper	$\frac{1}{581}$
Brass, mean of two specimens	$\frac{1}{532}$
Soft iron, forged	$\frac{1}{819}$
Iron wire	$\frac{1}{812}$
Untempered steel	$\frac{1}{927}$
Tempered steel	$\frac{1}{807}$
Lead	$\frac{1}{351}$
Tin of Falmouth	$\frac{1}{462}$
Silver	$\frac{1}{524}$
Gold, mean of three specimens	$\frac{1}{602}$
Platinum	$\frac{1}{1167}$

23. When we know the amount of elongation of any substance for a given number of degrees of the thermometer; its total increase in bulk may in general be calculated by multiplying the number which expresses its elongation by 3. Thus, if a bar of soft iron is lengthened by $\frac{1}{819}$ when heated from the freezing to the boiling point of water, its cubic space will have increased by $\frac{3}{819}$, or $\frac{1}{273}$ of its former capacity. This rule is not absolutely correct; but the error is so small, that in practice it may be altogether disregarded.

24. Since glass enters into the construction of thermometers, the rate of its expansion by heat becomes a matter of some importance. The following table will show the rates of expansion of glass, at some extreme temperatures. The first column indicates the temperature as ascertained by an air thermometer. The second shows the mean absolute expansion of glass for each degree. The third column gives the temperature as obtained by a thermometer made of glass. All the degrees are reduced to those of Fahrenheit's scale.

From 32° to 212°	$\frac{1}{69660}$	212°
32 to 392	$\frac{1}{65340}$	415·8
32 to 572	$\frac{1}{59220}$	667·2

* It has been remarked, that when an unannealed glass vessel is broken, the pieces do not fit together again.

25. From some careful experiments made by philosophers at various times, it has been proved that different solids do not expand to the same degree for equal additions of heat;—that a body which has been heated from the temperature of freezing to that of boiling water, and again allowed to cool to the freezing temperature, recovers precisely the same volume which it at first occupied;—that the expansion of the more permanent and infusible solids is very uniform within certain limits; their expansion, for example, from 32° to 122°, which includes a range of 90°, being equal to what takes place between 122° and 212°, which includes a similar range:—that solids do not expand uniformly at high temperatures, but in an increasing ratio: that is, beyond 212°, the higher the temperature, the greater is the expansion for equal increments of heat.

26. We have alluded to a remarkable property of tempered steel (20), and from what has been just said, it may naturally be inferred, that the uniform law of the expansion of metals, between 32° and 212°, does not apply to the tempered steel. Accordingly it has been found that tempered steel continually decreases in its rate of expansion from 32° to 150°. But it is a beautiful and remarkable fact, that this exception to a general law is, as indeed most exceptions are found to be upon close inspection, merely apparent. We remarked that the state of tempered steel was an unnatural state of forced expansion. When, therefore, the steel is gradually heated, it gradually recovers from this forced state, and becomes untempered steel, and in this state, which may be called its natural state, it obeys the law of equable expansion within the limits already assigned to the other more infusible solids.

27. There is an alloy, well known in science under the name of Rose's fusible metal*. It is composed of two parts bismuth, one part lead, and one of tin; this alloy melts at the temperature of $200\frac{3}{4}$°. It is a common trick to give a spoon made of this metal, to a person who has a cup of hot tea; on stirring which, the spoon gradually disappears. It has been proved that the density of this metal is greatest at $155\frac{3}{4}$°, and least at $110\frac{3}{4}$°. The fact is remarkable as appplied to a metal, that the specific gravity should be increased by increase of temperature. As the metal was raised from 32° to $110\frac{3}{4}$°, it was observed to expand almost uniformly, with the increase of tem-

* This alloy is sometimes composed of eight parts bismuth, five of lead, and three of tin. It is then called Sir Isaac Newton's fusible metal. If one part mercury be added to the alloy, it will melt considerably below 212°.

perature: but this expansion ceased at $110\frac{3}{4}°$; and the metal constantly contracted as the temperature was raised up to $155\frac{3}{4}°$, where the contraction ceased. By continuing the supply of heat, the metal began again to expand, slowly at first, but more rapidly as it approached its fusing point. At $178\frac{1}{4}°$, the density of the metal was nearly the same as 32°. No satisfactory explanation has yet been offered of this singular phenomenon.

28. Many bodies, on being cooled down to a certain point, change their liquid state for that of the solid; and a diminution in bulk is a frequent consequence. When olive oil freezes, it sinks through the unfrozen portion, thereby indicating an increased density. When molten gold and silver are allowed to cool, they diminish greatly in bulk. For this reason our gold and silver money is formed by stamping, and not by casting. But there are many cases, where the change from the liquid to the solid state is attended with increase of bulk; which we shall notice in our article on the Hydrometer (14), where the subject of liquid expansion will be noticed. The expansion of aëriform substances is also reserved for our article on the Hygrometer. (14, *et seq.*)

29. A remarkable discovery has been made by Professor Mitscherlich, on the subject of the expansion of solids by heat: namely, that the angles of some crystals are affected by change of temperature;—that crystalline bodies expand more in one direction than in another,—that at the time a crystal is expanding in length by heat, it may be contracting in another dimension. Thus an angle of rhomboidal calcareous spar varies $8\frac{1}{2}$ minutes of a degree between 32° and 212°. He also found that this unequal expansion does not occur in crystals of which all the angles and sides are alike; such as the cube, the regular octohedron, &c. It has been suggested to employ crystallized bodies in examining the laws of expansion by heat; since the expansions of a substance irregularly crystallized, may be various in various specimens, because the internal structure is not the same in all. This accounts for the discrepancies among the results of distinguished observers, on bodies apparently the same; which circumstance has hitherto prevented any general deductions from their useful labours.

30. In the arts, as well as in the concerns of domestic life, there are numerous instances (and often inconvenient ones,) of the effects of the expansion of solids. In buildings where much metal enters into the construction, space must be allowed for the expansion and contraction by changes of temperature both by night and by day; as well as at various seasons of the year.

We have heard of an engineer, who erected an iron bridge, upon which, when nearly completed, a few days of unusually warm weather produced so great an expansion and distortion of the metal work, as to endanger the building. It was, therefore, necessary for him to take the whole of it down, because he had not, in the first instance, allowed space for expansion. We have recently witnessed this effect on a railroad, where the iron rails were placed end to end, in close contact, during the winter of 1836. In the following summer, the expansion of the metal forced many of the rails from their sleepers, into a curved form; and the trains passing over them produced serious ruptures. The rails had to be relaid, because the engineer had not allowed room for expansion.

31. In our clocks and chronometers, &c., the expansion of the metal of the pendulums, and other parts, produces a serious effect upon the rate of going of those instruments; which, if not corrected, is likely, especially in navigation, to lead to disastrous consequences. Pendulums are generally made of metal; but wood has been successfully employed, and is perhaps to be preferred to metal, on account of its smaller expansibility by heat. The Royal Society of Edinburgh have lately employed in the construction of their clock, a rod of marble for a pendulum. In our article on the Pendulum, we shall enter fully into this subject; but we may here state that the rate of going in clocks, depends upon the length of the pendulum. When the latter is elongated by heat, the clock goes slower, and when contracted by cold, its motion is accelerated. If the bob of a pendulum, beating seconds, be lowered $\frac{1}{100}$th of an inch, the clock will lose ten seconds in 24 hours. A pendulum, whose length is 39·13929 inches, will gain $\frac{1}{128}$th part of an inch in length, by being heated 30° Fahrenheit, and this will occasion an error of eight seconds in 24 hours.

32. The staves of large casks, such as brewers' vats, are bound together by strong iron hoops, which are made too small to fit the cask in the first instance, but are heated until sufficiently large; they are then driven on the cask, and suddenly cooled; the contraction of the iron by cooling, brings the staves of the cask into close and firm contact, while the hoops themselves are tightly fixed.

Carriage-wheels are bound together in a similar manner; the iron tire is smaller than the wooden circumference of the wheel; this tire is heated, and then put on the wheel; by being suddenly cooled, it contracts, and firmly binds the felloes upon the spokes of that useful implement.

33. Glass is frequently broken by the sudden application of hot water. Glass being a bad conductor of heat, the surface in immediate contact with the hot water is expanded, while the opposite surface is scarcely affected; this unequal expansion of the two surfaces, produces a crack. Frequently the bottom of a stout glass comes out, by hot water being poured in; the sides not being heated, they retain their former dimensions, so that the expansion of the bottom forces it from the sides.

Such, then, is a brief view of the nature of expansion, and a few of its effects. Its application to the thermometer will be considered in the Second Section. We pass on, therefore, to consider another general effect of heat, under the term *Fluidity*.

34. When heat is communicated to a solid, the effect is, as we have seen, to expand it; and if the heat be sufficiently energetic, the solid is resolved into a liquid. The liquefaction of a solid is sometimes gradual, as when it passes through various degrees of softness; but generally it is sudden:—the solid is heated up to a certain point at which it remains solid; a very slight increment of heat is then often sufficient to liquefy it. In this case, the repulsive power of heat overcomes the cohesive attraction of the particles of the solid; and in proportion as the temperature is high, this attraction is diminished. When the particles of the solid are separated from each other, so as to move freely over each other, that state is acquired which we term fluidity. A large addition of heat would convert this fluid into an air or gas; and there is probably no solid substance which could not be resolved into the liqueform and aëriform states, provided we could command a temperature sufficiently high.

35. When, on the contrary, the temperature of a liquid is reduced, it gradually approaches that state at which the cohesive attraction of its particles is greater than the repulsive power of heat: the particles then become fixed, and the liquid returns to its solid state.

36. But there are certain important circumstances to be attended to in the process of liquefaction. It is obvious, that, if a mass of ice at a temperature of zero, or 0°, be taken into a room whose temperature is 60°, the ice can no longer retain its solid state; since above 32°, water is always liquid. It is an important principle of heat that it always tends to establish equilibrium in surrounding bodies: that is, if a hot body and a cold body be placed near each other, the latter will continue to abstract heat from the former, until the temperature of the two bodies is the same. We are in the habit of speaking of cold

and of warm bodies at the time when they are placed in precisely similar circumstances with respect to temperature. We place one hand upon a piece of iron, and the other hand upon a piece of flannel, and say that the former substance is cold and the latter warm. Now this is not so; it is a question of sensation merely, as we shall show further on (88). If these two bodies have remained for a time exposed to the same temperature, their temperature is the same. The ice, then, in the room whose temperature is 60°, will soon begin to melt; and a thermometer placed in it, which at first indicated 0° will slowly rise to 32°; at which point it will remain stationary until the ice has entirely passed into the liquid form. Even suppose that we place the vessel containing the ice upon a fierce fire, the mercury in the thermometer will not rise beyond 32° so long as a particle of ice remains in the vessel. In this observation it is manifest that whether the vessel remain in the room at 60°, or be placed over the fire, a quantity of heat must, in some way, combine with the ice in order to liquefy it, which heat the thermometer will fail to indicate. Hence we arrive at the important conclusion, that, during the process of liquefaction, a large quantity of heat disappears, of which the thermometer does not take cognizance*. Such heat is called *latent heat*, or heat not appreciable by the thermometer, or the senses; in contradistinction to *sensible* or *free* heat, which the thermometer and the senses can detect. From this we deduce another extraordinary fact, that, although ice at 32° and water at 32° *feel* equally cold, yet the latter contains a far greater quantity of heat than the former.

37. We will illustrate these conclusions by a few more examples. If a pound of water at 32° be mixed with a pound of water at 172°, the mixture will indicate the mean temperature of the two, that is $\frac{32 + 172}{2} = 102°$. But if a pound of water at 172° be added to a pound of ice at 32°, the ice will dissolve rapidly; but a thermometer placed in the mixture will indicate, not 102°, but 32°. So that the hot water actually loses 140°, and the ice appears to lose nothing, and to gain nothing of heat: but the fact is, that it gains 140° of *latent* heat; and in order to pass from water to ice again, it must part with this amount, before the pound of water at 32° which it has become, can be again a pound of ice at 32°.

* It is remarked that during a *thaw* the air has a peculiarly chilling effect; the reason is that a large portion of sensible heat is absorbed by the ice and snow in the process of liquefaction.

38. This sensible heat lost during the process of liquefaction, is sometimes called the *heat of fluidity*, and is different in different substances.

39. Since heat disappears during liquefaction, so heat is evolved when a liquid passes into a solid form. Water, in the act of freezing, always remains at 32°, although exposed to the temperature of 0°. Under such circumstances, the heat of fluidity is the only source by which the water can preserve its temperature: so that if pure and recently boiled water be slowly cooled, and kept quite free from every kind of agitation, its temperature may be lowered 10° or 11° below its freezing point without the formation of ice: but the least motion causes it to congeal suddenly, and then its temperature rises to 32°*.

40. The apparent loss of heat in the conversion of sensible into latent heat, is accounted for by Dr. Black, by supposing that in causing fluidity, the heat combines chemically with the solids:—that is to say, a liquid may be regarded as a solid chemically combined with heat; in the same manner, a vapour is a liquid chemically combined with heat. When a liquid becomes solid, its heat of fluidity, which was previously latent, is separated from such liquid, and becomes sensible to the thermometer; and without such separation, a liquid cannot be solidified. Again, on the other hand, when a solid is liquefied, a certain quantity of sensible heat combines with it in a proportion necessary to its state of fluidity.

41. The conversion of apparent into latent heat in the process of liquefaction, has been taken advantage of in many artificial cases for producing cold. All these cases depend for their efficacy upon the liquefaction of solid substances without the aid of heat; and the degree of cold depends upon the amount of the heat of fluidity which disappears, and this also depends upon the amount of solid matter which is liquefied, and the rapidity of the liquefaction.

42. A very common method of obtaining a low temperature is by mixing snow and salt together. The salt causes the melting of the snow by reason of its attraction for water, and the water thus formed melts the salt; so that both are liquefied. This process will sink the thermometer to 0°. Hence it is a dangerous practice to mix salt with the snow on our pavements for the purpose of liquefying it, unless it be swept

* When a cast of the face is taken in plaster of Paris, the moment the plaster *sets*, that is, *solidifies*, a sensation of great warmth is experienced.

away as soon as possible. So low a temperature affecting the feet of the passengers is a prolific source of colds.

43. There are various *freezing mixtures*, as they are termed, some of them more efficacious than others. A very remarkable cold produced in this way, is by mixing three parts by weight of crystallized chloride of calcium, with two parts of dry snow: this will sink the mercury in the thermometer from $+32°$ to -50, thus producing a degree of cold equal to $82°$ below freezing. The lowest temperature observed by Captain Parry at Melville Island during the winter of 1819-20, was $-50°$, and on one occasion, if we remember rightly, at a distance from the ships it was $-55°$.

44. The circumstances which attend the solidification of water, will be detailed in our article on the Hydrometer (16); but we may here very properly inquire into the phenomena which attend the passage of mercury from the liquid to the solid state. This subject becomes of more interest, since mercury is the fluid almost universally adopted in the construction of thermometers.

45. M. Braun of Petersburg, was the first philosopher who effected the congelation of mercury. He did so in consequence of the suggestions of Dr. Zeiher. Both these philosophers were professors in the Imperial Academy of Petersburg. On the 14th December, 1759, the temperature of the air being $-34°$, M. Braun prepared a freezing mixture, by mingling nitrous acid with pounded ice, into which a thermometer being placed, sank to $-69°$. In the hope of procuring a further reduction of temperature, and having exhausted his stock of pounded ice, he was fortunately compelled to employ snow as a substitute: with this mixture he sank the thermometer to $-100°$, $-244°$, and finally to $-352°$. On examining the mercury in the thermometer, it was found to be fixed, and it remained so for more than twelve minutes: on employing a thermometer which was graduated no lower than $-220°$, the mercury collected in the bulb, and remained solid as before.

Hence M. Braun concluded that the mercury had been frozen; and, in company with M. Epinus, on the 25th December he repeated his experiments, and as soon as the mercury became fixed, he broke the bulb of the thermometer, and obtained the mercury in the form of a solid, shining, metallic mass, which he found to be perfectly malleable, not quite so hard as lead, but yielding a dull, dead sound, like that metal when struck. M. Epinus remarked that the upper surface of the frozen lump of mercury was concave, and that pieces of it sank

in fluid mercury, which circumstances indicated its great contraction.

46. These philosophers, however, did not determine the freezing point of mercury, or that temperature at which it passes from the fluid to the solid state: this was determined by a series of admirable experiments performed in Hudson's Bay, by the directions of Mr. Cavendish, and with instruments furnished by him: these consisted of a glass cylinder partially filled with mercury, in which the bulb of a thermometer was placed so as not to touch the sides of the vessel: this apparatus was surrounded by a mixture of snow and nitrous acid, and the height of the mercury in the thermometer was noted as the mercury in which it was placed was cooled. It descended to $-38°{\cdot}66$, where it remained stationary, showing that this is the freezing point of mercury. Upon withdrawing the glass cylinder from the freezing mixture, it was found that the mercury was partially frozen. The cylinder was again replaced, and it was observed that the mercury in the thermometer remained quite stationary, until the whole of the mercury in the glass cylinder was completely frozen: then the mercury in the thermometer began to descend; and on becoming solid, underwent so sudden a contraction that it indicated a temperature of nearly 600° below the freezing point of water. Mr. Cavendish afterwards showed that mercury in the act of freezing contracts nearly $\frac{1}{23}$rd of its whole bulk. This circumstance accounts for the very low point to which the mercury in the thermometer sank, since a diminution in bulk of $\frac{1}{23}$rd part is equal to 452°.

47. We have now extended the subject of liquefaction as far as our limits will permit in the present article. The subject is exceedingly important, and the reader will do well to bear in mind the following points connected with the phenomena of liquefaction :—

i. That when a solid begins to melt, the temperature, as indicated by the thermometer, remains constant until the process of liquefaction is complete.

ii. That when a liquid passes into the solid state, the temperature, as indicated by the thermometer, remains constant, until the process of solidification is complete.

iii. That the same solid always becomes liquefied at the same temperature; and that the same liquid always becomes solidified at the same temperature; or, in other words, the melting and freezing points of the same substances are constantly the

same; whereas in different substances, solid and liquid, the melting and freezing points are different.

48. Ignition. When the temperature of a body is raised to a certain point, it becomes luminous. Such a body is then said to be *ignited*, or to be in a state of *incandescence*. By incandescence we mean *a glowing heat;* and this is altogether different from ignition, since in the latter process the body is chemically changed: and, generally speaking, a body can be ignited but once, whereas a body may be brought to a state of incandescence many times.

49. When a solid body, difficult of fusion, is heated in the dark, its increased temperature is announced by a dull red appearance, which gradually becomes brighter. If the red heat be continued, the red light passes to orange, then to yellow, and subsequently to bright white, resembling solar light. The body is then said to be *white-hot*.

50. It is difficult to ascertain the temperature at which red heat commences, but it has been supposed that it is the same in all bodies; and this temperature has been fixed at between 800° and 812°. This is a temperature beyond the range of the mercurial thermometer, because mercury boils at 662°; and in a state of vapour it cannot be employed as a heat-measurer. Recourse then has been had to an instrument called a *Pyrometer*, which we shall describe in the Second Section (184). By its means Mr. Daniell measured the lowest point at which a heated iron appeared red-hot in day light, and he found it to be 980°. But this must be considerably higher than the point of ignition of the same iron in the dark. Another difficulty arises from the varying acuteness of vision of differect observers. One may distinguish light proceeding from the heated metal, which light to another may be quite invisible. The melting point of antimony is said to be 810°, and this appears then visibly red-hot in the dark. Fusible metal when heated to 812° is also visible in like circumstances. The temperature of orange heat is said to be 1650°.

51. The points of fusion and incandescence seem to bear no relation to each other. Iron is incandescent in its solid state; while silver and lead may be melted without becoming luminous. Platinum may attain a clear white heat without fusion. It has been supposed that liquids under pressure may become incandescent. Mr. Perkins is said to have made water red-hot under intense heat and pressure. But in general, liquid bodies, together with some solids, as wood, &c., do not

incandesce; because they decompose before the necessary temperature is attained.

52. Gases do not incandesce: their temperature may be raised far beyond the point of incandescence without their becoming luminous; but a solid substance suspended in such heated gas, will immediately glow: a proof of the high temperature of the aëriform body. It is proper to remark, however, that some philosophers have considered *flame* to be incandescent gaseous matter.

53. It is not easy to ascertain the degree of heat produced by the direct rays of the sun, because it is apt to be dissipated as quickly as it accumulates. We have already noticed an experiment where the thermometer rose to 237° in solar light (8); and by employing a convex lens, a degree of heat can be obtained, which appears to be enormous. The most intense heat of our furnaces cannot vaporize gold; but Lavoisier by means of a powerful lens reduced this noble metal to vapour. A piece of silver held above the melted gold was sensibly gilded; whereas the greatest heat of a glass-furnace acting on gold for a month produced no sensible evaporation of that metal.

54. Count Rumford has shown that the heating power of the solar rays is not increased by collecting them in a focus; but that the intensity of their action is due to the number of them brought to bear upon one spot at the same time.

55. Of all the heavenly bodies, the sun appears to be the only one which supplies heat to the earth. The light of the moon, when concentrated 306 times by powerful lenses, is incapable of affecting the most delicate air thermometer. It has been shown by astronomers that the illuminating power of solar light is 300,000 times greater than that of the lunar rays. If the direct rays of the sun are capable, as it appears they are from Robison's experiment (8) of elevating the thermometer to 237°, supposing also the luminous and calorific power to be equal, then the lunar rays would produce nearly $\frac{1}{300000}$th part of this effect, which is equal to $\frac{1}{1250}$th part of a degree; an amount of expansion absolutely inappreciable by any means of observation that we possess.

56. Many of the properties of heat are identified with those of light and sound. Indeed, the undulatory theories of heat, light, sound, and of the waves of fluids, are the same. Heat and sound may be excited by percussion and friction; and both are communicated by contact and radiation. Light, heat, sound, and fluid-waves, are all subject to the same laws of

reflection. It is probable, therefore, that the undulations of some of the calorific rays must be less frequent than those of the extreme red or violet of the solar spectrum; and all such will be invisible. It has been conjectured that heat and light, if not absolutely the same, are at least convertible into each other: the difference consisting simply in the amount of vibrating force, or in the frequency of the vibrating pulses.

57. There is an extensive class of phenomena known under the term *phosphorescence*, which does not depend upon a high temperature for the exhibition of luminous properties. It was first announced by Boyle, that the diamond when slightly heated, rubbed, or compressed, emitted a light almost equal to that of the glow-worm. A large number of mineral bodies possess this property: fluate, phosphate, and chloride of lime; and most calcareous bodies possess it in a high degree. If chloride of lime be melted in its own water of crystallization, and then be viewed in the dark, it will glow with a lambent green light for a considerable time; and sparks and coruscations will be visible, accompanied by a crackling noise, due probably to the sudden and unequal contraction of the mass in solidifying. The sparks can also be obtained by striking it, or scratching it with a sharp instrument. The cause of mineral phosphorescence has been referred to electricity.

Phosphorescence often attends the progress of putrefactive fermentation. Decaying fish, and some kinds of meat, become luminous in the dark. If a portion of whiting, herring, or mackerel, be put into a phial, containing salt and water, the phial, in a few days, will exhibit a luminous ring on the surface of the liquid, and the whole liquid will become luminous by agitation. Freezing extinguishes this light; but it returns on thawing. It is augmented by a moderate increase of temperature; but the heat of boiling water destroys it. This light has no effect upon the most sensible thermometer.

58. Combustion. We have spoken of combustion as one of the effects of heat (14); but it would, perhaps, be more correct to say, that heat is one of the effects of combustion. Combustion is, in fact, a true chemical process; wherein two substances, at least, enter into combination, and heat and a new compound are only results. Thus, when antimony in powder, or copper in the form of thin leaves, is presented to chlorine, a combination is instantly effected between these bodies, and a chloride of antimony, or of copper, is the result, attended at the moment of combination with intense heat and light. The various substances which the material world presents

to us, may all be resolved into fifty-four simple bodies: (Introduction, 30:) these viewed with respect to combustion are either combustibles, or supporters of combustion. Nitrogen, perhaps, may be excepted. There are forty-two metals, all of which are combustible. Hydrogen, carbon, sulphur, phosphorus, selenium and boron, are non-metallic combustibles. It is difficult to assign a place to nitrogen, because there is some doubt whether this is not a compound substance. Of the fifty-four simple substances, then, there are five unaccounted for. These are the simple supporters of combustion; viz., oxygen, chlorine, iodine, bromine, and fluorine. Of these, the first is the most important. It is one of the constituents of the atmosphere, and of water. It enters abundantly into the composition of most bodies in their natural state; and indeed, it is so important a natural agent, that without it no animal could live, no plant could grow, and generally speaking, no flame could burn; for although there are four other supporters of combustion, oxygen is its most general supporter; and moreover, the four other substances would not support animal or vegetable life for a single hour.

59. It has been already stated (14) that no chemical combination is ever effected without a change in temperature. It is not meant by this, that the temperature is necessarily augmented; sometimes it is; but it may be lowered considerably, as we have seen in the case when salt and snow combine (42). But the temperature was elevated when chlorine was made to combine with antimony or copper (58.) Combustion, then, does not consist merely of that union of two bodies, by which the temperature rises, but of the combination of a combustible with a supporter of combustion. This even is not enough for the production of heat and light. It is further necessary that the combination be rapid. There are, indeed, instances of combustion, wherein the combination between the combustible and its supporter is exceedingly slow; but the result, in general, is the production of scarcely any light, and of no appreciable heat.

60. To an ordinary observer, combustion of matter, and its destruction, or even annihilation, are almost synonymes. The candle which illuminates his apartment, and the coals by which it is warmed, disappear, it is true; but, in nature, the term *destruction* is unknown. There may be vast and rapid changes, but no destruction; matter may, and does, enter into new forms, visible and invisible; it is constantly active in producing new combinations, but it is never destroyed.

Organic forms with chemic changes strive,
Live but to die, and die but to revive!
Immortal matter braves the transient storm,
Mounts from the wreck, unchanging but in form.

The matter of our candles and of our coals, from the solid is converted into the gaseous state, by combining with the oxygen of the air, which supports the combustion.

61. Before the discovery of oxygen gas, combustion was explained by one of those insufficient hypotheses which man so often invents to conceal his ignorance. He is always impatient that facts should remain unexplained; and rather than be without a theory, he will invent, and for a time be satisfied with, such a one as his ingenuity suggests. Thus, the creative fancy of the theorist once explained the phenomena of combustion, by supposing that all combustible bodies contained a certain principle, which was called *phlogiston*, the presence of which enabled bodies to burn. It was further supposed, that when a body burns, phlogiston is liberated; and that when a body had lost phlogiston, it ceased to be combustible. It was then said to be *dephlogisticated.* The heat and light which accompany combustion, were attributed to the rapidity with which phlogiston was evolved.

62. But according to this hypothesis, a combustible having undergone the process of combusion, ought to lose weight; whereas, it was found in many cases, that the results of combustion were heavier than before combustion had taken place. The discovery of oxygen gas soon proved fatal to the phlogistic theory. Lavoisier burnt phosphorus in a jar of oxygen, and observed that much of the gas disappeared, and that the phosphorus gained in weight; that the increase of the one was in the ratio of the loss of the other. Iron wire was burnt in oxygen gas, and the result was equal to the wire originally employed, in addition to the weight of the oxygen that had disappeared. Again, liquid mercury was confined in a vessel of oxygen gas, and exposed to a somewhat high temperature. The gas combined with the mercury; the resulting oxide was then heated to redness, when it was reconverted into oxygen gas and metallic mercury, the quantity of oxygen thus recovered answering precisely to that employed in the first instance to produce the oxidation.

63. When two bodies, by uniting together, become liquid, great cold is produced, as we have before noticed (42); and the degree of cold is proportional to the rapidity of liquefaction.

In chemical combinations where heat is evolved, the heat is proportional to the rapidity of combination; and it also depends upon the intimacy with which the two bodies combine. Increase of density is, therefore, the common result. Dr. Thomson gives an example which well illustrates this position.

Water is a compound of

2 Volumes Hydrogen gas
1 Volume Oxygen gas

united together and condensed into the liquid form.

Spec. Grav. of Hydrogen gas . .	0·0694
———— Oxygen gas . .	1·1111

that of atmospheric air being unity.

Now,

	Grains.
2 cubic inches of Hydrogen gas weigh .	0·043228
1 cubic inch of Oxygen gas . . .	0·346048
	0·389276

The weight of three cubic inches of the constituents of water before combination, is 0·389276 grains.

The weight of three cubic inches of water is 757·38 grains. Dr. Thomson says, "Now the volumes before and after combination are inversely as these weights. From this it follows, that 1700 cubic inches of the constituents of water, when they combine together, and assume the form of water, occupy little more than one cubic inch. So that the particles approach very nearly twelve times nearer each other than when they were in the gaseous state. This is an enormous condensation. Now the heat evolved, during the rapid union of oxygen and hydrogen gases is the greatest heat that we have it in our power to produce."

64. When a solid body is heated so as to produce light, we call the combined effects of light and heat, *fire;* if the body be gaseous, it is then called *flame.* Flame may be defined as the rapid combustion of gaseous or vaporous matter. The oil of our lamps, and the tallow of our candles are converted into vapour, before entering into combustion. This vapour is raised to such a temperature that it combines with the oxygen of the atmosphere; forming chiefly carbonic acid and aqueous vapour; and the heat evolved is such as to heat the vapour to whiteness, before its decomposition. Flame, then, is a luminous bubble of volatile combustible matter. It is a bubble, because combustion can only go on at the exterior, where it is in contact with the atmosphere. This bubble encloses a portion of hot, inflammable

vapour, which gradually forms part of the exterior of the flame, as successive portions are decomposed; and the results of such decomposition, or combustion, are dismissed into the air around. The supply of hot vapour diminishing as it ascends, the flame of a candle tapers to a point. If gunpowder be suddenly inserted into the interior of a flame, it will remain there for many minutes without exploding. This fact proves that flame is hollow, and that no combustion is going on in its interior. If a short piece of taper be lighted, and placed in a little dish containing spirits of wine, and if the spirit be ignited, so that the flame may entirely enclose the taper, the flame of this latter will be instantly extinguished. On blowing the flame of the spirit a little on one side, so as to admit the atmospheric air, the wick of the taper will be rekindled. This proves that the vapour within the flame is an inflammable non-supporter of combustion.

We shall probably exceed our duty if we inquire further into the interesting phenomena of combustion. There are many points connected with combustion upon which chemists are not agreed; and into which we cannot enter. The theory of combustion is not settled. The heat emitted during combustion, and which varies with the nature of the combustible, has been differently given by different authorities.

65. Before we proceed to notice the modes of diffusion of heat, we must inform the reader of some singular effects of heat upon different bodies.

It would be a natural conclusion, at first view, to suppose that, if equal quantities of heat were added to two substances, whose initial temperature was the same, they would be equally hot. But it may excite surprise when we say that there are probably no two substances, which, receiving heat from the same source, and to the same amount, become equally hot.

66. Suppose, for example, a pint of water at 100° be mixed with a pint of water at 40°, the resulting temperature will be the mean of the two, or $\frac{100°+40°}{2} = 70°$. But suppose a pint of mercury at 100° be mingled with a pint of water at 40°, the result will not be 70°, but 60°, so that the 40° lost by the mercury, heats the water only 20°. If we reverse the experiment, and mix a pint of water at 100°, with a pint of mercury at 40°, the result will indicate 80°; so that the 20° lost by the water, causes an elevation of 40° in the mercury.

If, instead of mingling these substances by measure, we take equal weights, the results will be still more remarkable and

instructive. Let a pound of mercury at 160° be added to a pound of water at 40°, the result will show a still greater disparity; the temperature of the mixture will be only 45°: but if the mercury be at 40°, and the water at 160°, the result will then be a temperature of 155°.

67. Or, suppose that, without mixing these two fluids, we have a quantity of mercury in one vessel, and the same quantity, by weight, of water in another vessel; that the temperature of the two fluids is 50°; and that we wish to raise both to 60°; and lastly, that we apply equal flames to the vessels. If we observe the time during which the mercury rises through 10° to be one minute, we shall find that it will take nearly thirty times as long to raise the water to the same temperature; that is, the mercury is heated in one minute, as much as the water is in half an hour.

68. Different bodies manifest various degrees of susceptibility to heat. To produce a certain change of temperature requires a greater supply of heat in some bodies than in others. The quantities of heat necessary to produce the same change of temperature in equal weights of different bodies, are called the *specific heats* of these bodies. Sometimes the term *capacity* is employed. One body is said to have a greater capacity for heat than another. If the quantity of heat necessary to raise pure water through 1° of temperature be expressed by 1000, then 33 will express the capacity or specific heat of mercury, or the quantity of heat necessary to raise the temperature of mercury 1°; or if we call the specific heat of water 1·000, then that of mercury will be ·033, platinum ·0314, copper ·114, and so on. We see then, that water has a far greater capacity for heat than any of the other bodies just named; whereas, the specific heat of mercury is exceedingly small. This circumstance is one of the many advantages arising from the adoption of mercury in the construction of thermometers. A very small quantity of heat produces a great effect on this fluid metal: whereby its sensibility as a heat-measurer is greatly improved. Another favourable property of mercury is that its medium specific heat between 32° and 212° is constant, and may be expressed by the number 33; that of water being 1000. Its specific heat between 212° and 472° is different only in a slight degree; which, in practice, may be neglected. Between the two latter temperatures, the specific heat is expressed by 35. We should here remark, that it is supposed that all bodies undergo an increase in specific heat as their temperature is raised.

69. The specific heat of various bodies is supposed to be constant in the same body only at the same temperature. It is greatly affected by density. If the density of a body be diminished, its capacity for heat is increased; and *vice versâ*. If sulphuric acid and water be mixed at 50°, the temperature of the dilute acid immediately becomes 220°; or even 300°. We find that this mixture is denser than the sum of the densities of the two liquids in a separate state; but, in respect of the capacity for heat of this mixture, if we take the capacity of sulphuric acid at 429 and that of water at 1000, the blended capacity of these substances is not the mean of the two, 714; but 605. It follows therefore, that the dilute acid has not capacity to contain the quantity of heat which exists in the two liquids separately; and hence part of such heat is rendered sensible. Or, as an easy illustration, we may suppose a gallon measure full of water to be suddenly reduced to the capacity of three quarts;—the capacity of the measure would not then be equal to a gallon but only to three quarts, and one quart would necessarily flow over. Similar phenomena result from the compression of solids if a piece of metal be suddenly compressed, it becomes hot; because its capacity for heat is said to be diminished; and in its condensed state, we may suppose that it contains less heat than it did previously to the compression.

70. So also aëriform bodies, as we have already seen (12), if suddenly compressed, give out heat. In this case their capacity for heat is diminished; whereas, if air be suddenly expanded, its capacity is increased. A striking example of the latter effect occurs at the mines of Chemnitz, in Hungary. A Hiero's fountain is employed as part of the working machinery of the mine; where a perpendicular column of water, 260 feet high, presses upon a quantity of air in a close vessel. The air being under this pressure rushes forth when the stop-cock is opened; and expanding in its escape, produces so great a degree of cold, that the aqueous vapour mingled with it congeals into a shower of ice and snow. The force of the blast is so great that the workman, who holds a hat whereon to collect a compact crust of snow, is obliged to rest his back against the wall to retain the hat in its position. Sometimes solid lumps of ice pierce the hat as if they were bullets projected from a pistol.

71. Steam rising from water in an open vessel, will scald a hand held in it: but if steam under pressure, at a temperature

considerably above the former, be suddenly liberated, it will appear scarcely warm; because its sudden expansion greatly increases its capacity for heat.

72. It is a common remark with travellers, that the wind which blows down from the snow-clad mountains is often mild and even warm. This may be explained on the principle of change in capacity: for although the air at the mountain-top is cold, it is much rarefied, and has a great capacity for heat. It also contains much heat in a latent state:—but when driven down towards the valley, the air is condensed; its latent heat becomes sensible, and it is felt to be a warm breeze. If the warm air from the valley blow upwards, it produces a sensation of cold; because it expands, and its capacity is increased.

73. It is difficult to determine with precision the specific heats, or capacities, of various bodies. Three methods have been adopted; but all of them are more or less fallacious. The *first* method consists of mixing bodies at various temperatures, and applying the following rule: Multiply the weight of each body by the number of degrees between its original temperature and the common temperature obtained by the mixture: the capacities of the bodies will be inversely as the products. The *second* method consists of employing an instrument called a *calorimeter* (from *calor*, heat; and $\mu\epsilon\tau\rho\epsilon\omega$, to measure), which is constructed on the principle that a certain weight of ice at 32° requires, in order to be melted, the quantity of heat which would raise an equal weight of water from 32° to 167°. We have already given examples of the first method. We will give an illustration of the second. If an ounce of mercury and an ounce of water be placed in the calorimeter, which contains ice at 32°, it will be found that in falling from 60° to 55° they will melt quantities of ice in the proportion of 33 to 1000, or nearly as 1 : 30; so that in order to raise water from 55° to 60°, a greater quantity of heat is required than to raise an equal weight of mercury through the same range of temperature; and this quantity will be in the proportion of 30 to 1.

74. The *third* method of ascertaining the specific heat of bodies, is to raise them up to a certain temperature and observe the times which they respectively occupy, under the same circumstances, in cooling down through a certain number of degrees. Many of our readers may probably have noticed the rapidity with which the mercury in a thermometer descends, that is, *cools*, on being withdrawn from a source of heat considerably higher than that of the surrounding air. Now, according to what has been said, it will follow that if water and

mercury be heated from 55° to 60°, and if the mercury regain its former temperature in one minute, the water will occupy thirty minutes in descending 5°. By observing the rate of cooling, Dulong and Petit determined the capacity for heat of the following substances, water being 1000.

	Specific heat.		Specific heat.
Sulphur . . .	188	Silver . . .	56
Glass . . .	117	Mercury . . .	33
Iron . . .	110	Platinum . .	31
Copper . . .	95	Lead . . .	29
Zinc . . .	93		

75. In our article on the Hydrometer (32) we have said that the specific gravity of a substance is not its weight, but simply its density, as compared with an acknowledged universal standard; and this standard we stated to be pure water at 60°. In like manner, in ascertaining the specific heat of bodies, we do not arrive at a knowledge of the absolute quantity of heat which they contain, for that would be impossible; but we simply refer them to a given standard of universal application—this also is pure water. We are entitled to fix as a standard any substance, which, under precisely similar circumstances affords the same results: and in this way it is that, by constant experience, founded upon fore-knowledge of the same or collateral evidence, we understand and interpret the laws of nature; and are always enabled to decide what effects will happen upon any proposed data, provided such effects have been observed before.

76. The specific heats of aëriform fluids have been estimated by heating each gas to 212°, and transmitting it in an uniform current through a curved tube surrounded by water, the temperature of which is accurately determined at the beginning and end of each experiment, and then ascertaining the quantity of each gas that must be employed to raise the water to a given temperature. The following are a few examples :—

Water . .	1·000	Air . . .	0·2669
Hydrogen . .	3·2936	Oxygen . . .	0·2361
Aqueous vapour .	0·8470	Carbonic acid .	0.2210
Nitrogen . .	0·2754		

77. It is difficult to account for the varying capacities of different bodies for heat. It has been supposed to depend upon the amount of porosity, or vacant space, which they afford to the entrance of heat, supposing heat to be a fluid; and accordingly the denser a body is, the less vacant space will it present and the smaller will be its capacity for heat. Mercury

is much denser than water and its capacity is far less than that of the latter fluid. Bodies increase in capacity for heat by rarefaction; because, it is said, heat has more room to enter. But numerous objections oppose this theory.

78. *Diffusion of Heat.* We have said that heat is diffused, or propagated, in two ways (7): by *conduction* or *contact;* and by *radiation.* We proceed to illustrate the first method.

Material substances of every description may be considered as so many paths through or along which, heat travels, or is conducted. The rapidity with which heat travels varies in various substances. In some cases its passage is almost instantaneous; while in others it is only appreciable after a considerable lapse of time. The former substances are called *good conductors* of heat, and the latter *bad conductors.*

79. If we thrust into the fire two rods of a certain length, one of iron and the other of wood, we shall find that the iron will soon become too hot to be held; but that the wood will scarcely be felt to be heated. The experiment may, however, be tried in a more instructive manner. Provide two cylinders of similar size, the one of iron and the other of wood: fold tightly over both, one or two turns of clean writing-paper; and secure them near one end with string. Hold that part of the iron cylinder which is covered with paper in the flame of a spirit-lamp; (this flame is preferred because it deposits no carbon;) and it will be found impossible to burn, or even scorch or singe, the paper, before the cylinder shall have become far too hot to hold; whereas the paper on the wooden cylinder will be blackened and burnt immediately.

80. These two experiments inform us, that iron is a good, and wood a bad, conductor of heat. In the first case, the heat travels rapidly up the iron rod to the hand; which is not the effect with the wood. In the second case, the heat passes so rapidly through the paper in its passage to the iron, that the paper is left too cool for combustion: the flame (so to speak) has not time to burn the paper, on account of its rapid conduction; but wood conducts heat so slowly that it does not cool the paper, and the flame acts at once with full effect upon the wooden rod and upon the paper which surrounds it.

81. Among solid bodies, the metals are the best conductors of heat, and these again vary in conducting power. The following experiment displays in a striking manner the conducting capabilities of some of the metals.

Upon a suitable frame-work let two circular and concentric supports be made to hold, in a horizontal position, a slip of each

of the following substances; gold, silver, copper, iron, lead, and porcelain. At the outer end of each slip a piece of phosphorus is placed. Below this arrangement let the steady flame of an argand lamp play upon equal portions of the inner ends of the six substances named above: the phosphorus upon the gold will soon be kindled; then will follow that upon the silver, the copper, the iron, and the lead; but the phosphorus upon the porcelain will probably not be kindled at all. If in place of the phosphorus, the bulb of a small thermometer be brought in contact with the outer ends of slips of the metals contained in the following table, the extent of the conducting power of each metal will be represented by the corresponding numbers which indicate the degree to which the respective slips would raise the thermometer in equal times.

Gold . . .	1000	Tin	303·9
Silver . .	973	Lead . . .	179·6
Copper . . .	898·2	Marble . . .	23·6
Platinum . .	381	Porcelain . .	12·2
Iron . . .	374·3	Fine Clay . . .	11·4
Zinc . . .	363		

82. Wood is a bad conductor of heat, but its power this way depends greatly upon its density; the conducting power bearing some sort of inverse ratio to its density. The dense woods conduct heat worst: this rule is not, however, without many exceptions; since the conducting power of hazel is superior to that of oak, and the apple-tree wood is superior to ebony. In all these cases, heat is conducted with more facility in the direction of the fibres than across them.

83. The experience of mankind with respect to clothing has been proved to be accurate, by some experiments of Count Rumford. He enclosed a thermometer in a glass cylinder, blown into a ball at its lower end, and filled up the vacant space with the substance to be examined: he heated this apparatus in every case by immersion in boiling water, and then placed it in melting ice, noting carefully the number of seconds which elapsed during the fall of the thermometer through 135°. When air only was between the thermometer and the cylinder, the cooling occupied 576″ of time; when the vacant space was filled with fine lint, it occupied 1032″; with cotton wool 1046″, sheep's wool 1118″, raw silk 1284″, beaver's fur 1296″, eider down 1305″, hare's fur 1315″. These results show us that nature clothes an animal with a badly conducting material, to prevent the escape of heat; and the varying dresses of the superior animal, man, are adopted with a view to their con-

ducting power. Badly conducting materials form his dress in winter, so as to retain as much as possible, his animal heat; and in summer, the material adopted is generally of such a nature as will conduct heat with greater rapidity, in order that the superfluous heat of his body may be thrown off.

84. Liquids appear, on a superficial view, to conduct heat rapidly; but in fact they are very imperfect conductors. The mobility which exists among all the particles of liquid bodies, causes a liquid whose parts are unequally heated, to arrange itself into distinct strata; so that the particles of a higher temperature, becoming by expansion specifically lighter than the particles a few degrees lower in temperature, occupy a superior place in the containing vessel. If heat be applied to the bottom of a vessel, as in boiling, the lower particles, rendered lighter by heat, ascend; and the higher and denser, because colder, particles descend: and thus a series of currents is established, which circulate with a rapidity proportionate to the temperature. But this example by no means proves water to be a good conductor of heat: it is simply a question of varying density, due to expansion from heat. A good conductor of heat, such as gold, will conduct equally well if the source of heat be above, below, or on one side; but if a liquid such as water be heated from above, the superior stratum of particles becomes heated, it is true, but there is scarcely any transmission of this heat to the inferior particles, and a thermometer placed below the surface, will not indicate an increase of temperature.

85. We must consider heat, when propagated by conduction, to issue from particle to particle in the following manner. The first particles in contact with the source of heat, acquire an elevated temperature, which is greater than that of the contiguous particles; and so, an interchange, tending to equilibrium, ensues between them. But equilibrium cannot be at once attained; because, the first particles being in contact with a source of heat and receiving more heat than can occupy their vacant spaces, this surplus is given to the second particles; and they in like manner becoming saturated, (so to speak,) affect the third particles; and so on to the end.

86. Liquids were once supposed not to conduct heat at all; but it is now admitted that they do conduct heat, but very slowly. If a long cylindrical glass vessel be filled with water, and a lump of ice by being attached to some heavier body, be sunk to the bottom, and if the vessel be inclined, and a flame applied near the top, the water there may be made to boil without affecting the temperature of the ice beneath.

87. It is not easy to estimate the conducting powers of aëriform bodies. The moment a particle of air is heated, it expands, and ascends with velocity, in consequence of the denser and colder air pressing upon it, and forcing it upwards. It is supposed that airs conduct heat, but in a manner inferior to that of liquids.

88. The fallacy of the evidence afforded by our senses, is very conspicuous, when heat is the subject of investigation. It requires an effort of reason to become assured that a piece of what we call *cold marble*, and a blanket when placed in the same circumstances, are of the same temperature. It is true that one conveys a sensation of cold, and the other of warmth, but it must be carefully borne in mind, that this difference depends solely upon the various conducting powers of the two bodies. If we place our hands in water at 90°, we decide that it is warm; but if we place one hand in water at 150°, and the other in water at 40°, and after a short interval immerse both again in the water at 90°, this water will feel cold to the one hand and warm to the other: to the hand heated by water at 150°, water at 90° feels cold; and the hand cooled by water at 40°, feels water at 90° to be hot. We cannot therefore well admit the senses always to decide in such matters, since they lead to the conclusion that water at 90° is both cold and hot at the same time.

89. We have hitherto spoken of the propagation of heat, when the heated body is in direct *contact* with the source of heat; but the reader is well aware that in order to feel the sensation of heat, contact is by no means necessary. We stand at a considerable distance from a fire, and experience its warmth: and this effect we know is not due to a hot current of air, since whatever current there may be, sets in, in an opposite direction; that is, *towards* and not *from* the fire: and again, heated particles of air have a common tendency to rise upwards, and not to advance towards us in a horizontal direction. Nor can it depend upon the conducting power of the air, since aëriform bodies conduct heat very slowly; and the effect of heat from a fire is instantaneous. It cannot be conducted by the air, for another reason, namely, that heat is propagated even *in vacuo*, as well as in every kind of gas. From all this it has been inferred, that a substantial medium, path, or passage is not necessary for the propagation of heat. Heat then distributed in this manner is called *radiant* or *radiated heat;* and the process by which it is distributed is called *radiation.*

90 If a cannon-ball be heated, and suspended in such a

manner as to be unaffected by currents of air, except the ascending current of hot air which it generates, rays of heat will be emitted from it as a centre in radial lines, which proceed with the velocity of light, and like luminous rays may be reflected, absorbed, refracted, transmitted, and polarized, by encountering certain surfaces. It is not necessary that the ball be red-hot; if its temperature be above that of the surrounding air, rays of heat, although unaccompanied by light, will continue to issue from it, until its temperature is the same as that of the surrounding medium. If such rays fall upon a reflecting surface, or upon a surface through which they can be transmitted, reflection and transmission ensue, without disturbing the temperature of the reflecting and transmitting bodies: but if the calorific rays be absorbed, an immediate increase of temperature in the absorbing body results. Daily experience assures us, that both heat and light diminish in their intensity, as the distance from the source of either is increased; and the rate of diminution is regulated by a law which applies very extensively to those forces, which proceed from a centre; viz., that the increase or decrease of intensity follows the inverse ratio of the square of the distance. The intensity of radiant heat, therefore, diminishes in the ratio that the squares of the distances from the radiating point increase. Now, with our suspended cannon-ball, if we could avoid the ascending current of heated air, we should find that a thermometer placed at any number of equal distances from the centre of the ball, would give precisely the same temperature. If the thermometer indicated 400° at one inch from the surface of the ball, the intensity of the heat of the latter would decrease at two, three, four, and five inches respectively, in the proportion of the squares of those numbers.

91. It is remarkable, that the rate at which a body cools is influenced by the state of its surface, more than by the nature of the material of which it is composed. This curious fact is due to Leslie. He filled a bright tin vessel with hot water, and observed the time it occupied to cool in still air. A thermometer placed in the water sank half its way down to the temperature of the air, in 156′. The same vessel was then covered with lamp-black, and the experiment repeated with hot water at the same initial temperature. This cooled down to the same point in 81′; the rate of cooling being nearly doubled, simply by changing the nature of the surface of the containing vessel.

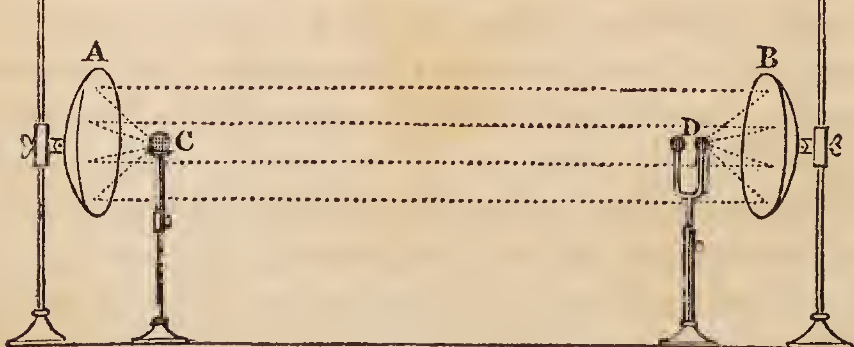
92. Rumford placed water of the same temperature in two equal glass cylinders; one of which was covered with a tight

linen bandage. The water in the covered vessel sank 10° in 36½ minutes: the water in the uncovered vessel sank 10° in 55 minutes. The cooling was also hastened by covering the cylinders with lamp-black, or white paint.

93. In estimating the radiant power of different surfaces, Leslie employed a hollow tin cube filled with hot water, whose surfaces were variously coated. The rays proceeding from any particular side, were brought into a focus by means of a concave mirror, and the bulb of a differential thermometer (167) was placed in the focus. The rationale of this experiment is as follows. In the article on the Prism it will be seen in what manner rays, which proceed in parallel directions from a luminous body, to a concave mirror, converge by its means to a focus in front of the mirror, after reflection. Now, precisely the same effect is produced on radiant heat, when it impinges on a concave mirror or reflector; so that the heating effect is greatly increased. The heat-measurer, therefore, which is the differential thermometer, is placed in that particular spot at which the calorific rays will focalize; and the vessel of hot water is placed at some distance beyond the thermometer, and in a line with its centre. When, therefore, rays of heat proceed from the vessel to the mirror, they are reflected and focalized at the spot occupied by the bulb of the thermometer, which is thus affected in its indications. When different sides of the cube were presented to the mirror, Leslie found that the indications of the thermometer were more or less rapidly affected, according to the radiating power of the surface.

94. Two concave mirrors placed exactly opposite each other, are sometimes employed for performing numerous striking class-experiments. The following figure represents the arrangement.

Fig. 1.



A heated body, such as a small globe of hot water C, Fig. 1, is placed in the focus of the concave mirror A. The bulb of a differential thermometer D, is in like manner placed in the focus of the concave mirror B. Now the hot body radiates, in

all directions, that portion of its heat which is above the temperature of the surrounding air: some of the rays therefore impinge on the mirror A. Now as parallel rays converge to a focus, after reflection from the mirror; so, conversely, are rays which emanate from such a focus converted into parallel rays after reflection. The rays of heat are by this law reflected from one mirror to the other. Here a second operation of the law of reflection takes place, and the rays are focalized at the point D, where they influence the thermometer in the manner before described. This is a very pleasing illustration of the law of reflection, as rays of light are influenced in precisely the same manner.

95. This effect may be strikingly varied by suspending a red-hot ball at C, instead of employing a globe of hot water; and by substituting for the thermometer at D a portion of phosphorus, amidou, ether, gunpowder, or other inflammable substance. The radiant heat from the ball will, after two reflections, be sufficient to ignite the combustible. The distance between the two mirrors may be fifteen or twenty feet, provided the apparatus be good of its kind. If the mirrors radiate heat but feebly, and the substances mentioned above be not ignited, phosphorus, dissolved in sulphuret of carbon, is almost certain to be ignited: but if the mirrors be well polished and accurately placed, and the source of heat and the inflammable substances be placed accurately in the respective foci of the two mirrors, there is no chance of failure. In adjusting the mirrors, a small hole is generally provided in the centre of each; so that the flame of a taper, placed behind one mirror is distinctly visible to an eye placed behind the other mirror, if the mirrors be of the same height and parallel with each other.

A candle is sometimes placed in one focus, and is kindled apparently by the radiant heat of the hot ball in the other focus; but, in order to effect this, the wick must contain a piece of phosphorus, or be steeped in a solution of phosphorus in sulphuret of carbon:—this is one of the artifices of the scientific lecturer.

96. The radiating power of various surfaces, as ascertained by the canister-cube, may be thus stated:

Lamp-black	100	Mercury	20
Writing paper	98	Clean lead	19
Sealing-wax	95	Polished iron	15
Crown-glass	90	Tin plate, gold, silver, copper, all polished	12
Plumbago	75		
Tarnished lead	45		

97. Pictet endeavoured to measure the velocity of radiant heat. He placed two mirrors, as in the last figure, opposite each other, at a distance of 69 feet; a heated ball being in the focus of one, and a delicate thermometer in that of the other, and a screen between them. At a given signal the screen was suddenly withdrawn, and at the same instant the thermometer was observed to rise. This proves that the calorific rays passed through a space of 69 feet, during an interval of time too small to be measured. As radiant heat moves with light in the solar beams, it must have the same velocity, *i. e.*, 190,000 miles in a second of time, and cannot therefore be estimated at short distances.

98. If, instead of a heated ball, in the last experiment, we place in the focus of the mirror a ball of ice, the thermometer in the other focus will be observed to sink, as in the last experiment it was observed to rise. Now it must not be supposed that, because a rise in temperature was assigned to radiation of heat, a corresponding fall is due to radiation of cold. No principle of cold, considered by itself or abstractedly, can be admitted —since cold is merely a sensation arising from abstraction of heat; as darkness results from absence of light, and silence from absence of sonorous vibrations. In the last experiment, the thermometer sinks because it radiates heat to the ball of ice:—it parts with heat in fact, and therefore its temperature declines.

99. The theory of radiant heat which is now generally admitted, is due to M. Prevost. He supposes that all bodies are constantly radiating heat around them, and that the amount of radiation depends upon their temperature. A number of bodies which are of the same temperature radiate heat to each other reciprocally; and, in like manner, receive equal portions of heat, so that their temperature does not fall. If a body of a higher temperature be introduced among them, they radiate heat to it, but it radiates heat to them in larger quantity than it receives heat itself; and therefore its temperature falls and that of the other bodies rises, until an universal equilibrium is effected. If, on the contrary, a colder body be introduced, it receives heat from the other bodies in greater quantity than it gives; so that its temperature becomes eventually the same as that of the others. The temperature therefore of a body is stationary, only when it receives as much heat as it radiates.

100. In the experiments which we have just announced, the radiant heat impinging on the surface of the mirror, is

reflected to the focal point; where it is transmitted through the glass surface of the thermometer, and absorbed by the fluid within, or is absorbed by certain substances to such an extent as to cause their ignition*. We must therefore consider this property of radiant heat, viz., *reflection*, as also its *absorption*.

101. The reader may assure himself of the reflection of heat, even when unaccompanied by light, for in this state the reflection of heat is, perhaps, most convincingly shown, by placing a bright surface opposite any source of heat, at such an inclination as will receive the incident ray at a large angle, and reflect it to a spot where the observer is quite out of the reach of the direct radiant heat.

102. Or, a screen may be placed between the heated body and the observer, so as to intercept entirely all direct radiant heat, in the following manner. In front of the reflecting surface, and at right angles to it, but not in contact, may be placed an opaque screen. On one side of the screen is a red-hot ball, and on the other a differential thermometer. Rays of heat, impinging on the reflecting surface, will be reflected from it at angles equal to the respective angles of incidence. The meaning of this law will be more fully explained in the article on the Prism; but the fact which we have to notice in this place is, the rise of the thermometer, by the influence of the rays of heat which have been reflected from the polished surface:—the

* We cannot take leave of these illustrations of radiant heat, without reminding the reader of the strong analogy with it existing in the science of sound, and of optics, when concave mirrors are similarly employed. If, instead of the hot ball set in the focus of one mirror, we place a watch or a small bell, the sound will be condensed by the opposite mirror; and an ear, placed in the focus of the latter, will be sensible of a great increase of sound. The sonorous waves, propagated from one focus, strike against the nearer mirror, and are reflected from it to the face of the opposite mirror, and concentrated by a second reflection into its focus. So, also, if a bright light be placed in the focus of one mirror, it will be condensed in the focus of the opposite mirror. So, also, with liquid waves:—if the mirrors be placed opposite each other, and submerged, one half, in a channel of still water, a disturbance of equilibrium in one focus, will generate a system of waves, which will be reflected by the one mirror to the opposite mirror, and which will all meet and terminate in the focus of the latter. In like manner, the transmission of heat from the focus of one mirror to that of the other, may be conceived to be due to the propagation of similar undulations, through another medium different from air, but coexisting in the same space: or, if we do not admit the existence of a distinct fluid for heat, but adopt the undulatory theory, we must refer the different properties of heat to differences in the size of the waves, and to the varying velocity and extent of the calorific vibrations.

interposition of the screen tending to show, that the rise was not occasioned by direct radiation from the hot body to the bulb of the thermometer, but that it was wholly due to those rays which had been reflected.

103. If, instead of the concave metal mirrors, (94,) similar mirrors of glass had been employed, the effect upon the thermometer, &c., would have been far less; and if the metal mirrors had been coated on the inside with lamp-black, no effect whatever would have been produced upon the thermometer. We see then that, as different surfaces have different powers of radiation, so are the powers of reflection dependant upon the nature of the reflecting surface. The reflecting powers of various bodies have been determined by Leslie. We give a few results.

Brass	100	Lead	60
Silver	90	Glass	10
Tin-foil	85	Glass covered with wax or oil	5
Steel	70		

104. On comparing this table with that of the radiant powers of similar surfaces, it will be seen that those surfaces which are the best radiators are the worst reflectors, and *vice versâ*. The power of radiation is inversely as that of reflection; so that bright, smooth surfaces, as of polished brass, silver, steel, &c., which are retentive of their own heat, are not apt to receive heat from radiating sources, but reflect such rays as impinge on them; while, on the other hand, that state of surface which facilitates radiation, is ill adapted to reflection.

105. When rays of heat fall upon any surface, and are perfectly reflected, the temperature of such surface remains the same; but if part only of the rays be reflected, it is clear that the remaining or supplemental part must be absorbed. It follows, also, that as the reflecting powers of any surface depend upon the nature of such surface, its absorbing powers depend upon the same cause. Those superficial qualities which promote reflection, must be inimical to absorption; and *vice versâ*: and, since the radiating power is in an inverse proportion to that of reflection, so is the radiating power in a direct proportion to that of absorption. This inference is well demonstrated by an experiment of Professor Ritchie; who, we lament to say, must be spoken of as one of the past. The instrument with which he performed the experiments from which this inference was drawn, consisted of a large, differential thermometer, with cylindrical chambers, made of the thinnest tin-plate. The horizontal branch of the glass tube was about a foot long; and the vertical portion at each end was about five inches high, having a bulb

blown at its extremity. On each of these two bulbs was placed a cylindrical chamber, about three or four inches in height, and half an inch in diameter; and the open ends of the bulbs were soldered to rims in the bottom of the cylinder. Half of the surface of each of the cylindrical chambers was coated with lamp-black, and the other half was bright. The liquid contained in the glass tube was alcohol; and a small scale was attached to the middle of the tube. Another cylinder or canister of tin-plate, of the same length and diameter as the chambers, coated on one side with lamp-black, the other being left bright, was then filled with hot water, and placed midway between the chambers. When the coated side of this canister was turned opposite to the coated side of one of the chambers, the fluid in the opposite stem sank with great rapidity. "The reason of this," says Professor Ritchie, "is obvious: from the coated side of the cylindrical canister, we have an immense quantity of radiant heat shooting out at right angles to the surface, and falling on the powerfully absorbing surface of the cylindrical chamber of the instrument; whereas from the opposite metallic surface of the canister, we have a very scanty portion of radiant heat; and that, too, falling on a surface which absorbs only a minute portion; hence the striking difference between the temperature of the air in the two chambers of the thermometer."

Remove the canister, and again place it exactly in the middle between the two chambers as before, with its coated side turned towards the bright side of the cylindrical chamber, and its bright side towards the coated surface of the other chamber; fill it with hot water, and the liquid in the stem will be found to remain *perfectly stationary*. The reason of this beautiful result is equally obvious. From the coated surface of the canister we have a copious flow of radiant heat, suppose ten times as much as from the metallic surface, which falls on a surface of feeble, absorbing power, which we shall suppose takes in only one part out of ten of the whole radiant stream; from the other side of the canister we have only a very small portion of radiant heat, which we suppose equal to one, which portion is absorbed by the coated surface of the chambers, and rapidly conveyed to the included air; and since the effect on both chambers is the same, we conclude the radiating and absorbing powers are exactly equal to each other. If the surfaces be scratched or coated with other substances, the same law will be found uniformly to obtain.

106. The effects of reflection and absorption of heat may be strikingly shown by the following contrivance: Let there

be placed opposite to each other, two equal discs of tin, of which the surfaces of one are bright and polished, and those of the other are covered with lamp-black, mixed with a little gum water, and applied with a brush. Behind each disc let there be a small shelf; and place on each shelf a piece of phosphorus This arrangement being complete, let a hot cannon-ball be placed midway between the two discs: the phosphorus behind the blackened disc will almost immediately begin to fuse, and soon be inflamed, owing to the absorption of heat by the black disc; whereas the bright surface of the other disc will reflect the heat, so that the temperature of the phosphorus behind it will not be raised, and consequently cannot be inflamed.

107. By means of a delicate instrument (192), Messrs. Nobili and Melloni have shown that the radiating and absorbing powers of surfaces for simple heat, are in the inverse order of their conducting power.

108. Radiant heat passes freely through a vacuum; and the impediment offered to its progress by gaseous bodies generally, is so small, that its amount has not been ascertained. Transparent media of greater density, however, greatly impede its passage, and when of a certain thickness, prevent its transmission altogether. Melloni has succeeded, (if we may be allowed the expression,) in filtering light, (whether of the sun or of ordinary fires,) from heat, so completely, that a brilliant focus of light is collected; and strange as it may appear, such focus, however brilliant to the eye, seems to be so destitute of heating rays, that a most delicate thermometer placed in it is quite unaffected.

109. The property which some bodies possess of transmitting heat, does not seem to depend upon their transparency: that is, bodies are not transparent to heat in the same ratio as to light. Melloni found that plates of certain minerals of the same thickness, allowed very different proportions of heat from the flame of an oil lamp to pass through them. Thus, of 100 rays incident upon the following surfaces, there will be transmitted by

	Rays		Rays
Rock-salt . . .	92	Emerald . . .	29
Rock-crystal . . .	62	Sulphate of lime . .	20
Do. of a smoky brown colour,	57	Fluate of lime . .	15
Carbonate of lead . .	52	Alum	12
Sulphate of barytes . .	33	Sulphate of copper . .	0

110. In the filtration of light, where the whole of the heat seemed to be arrested, a peculiar kind of green glass was em-

ployed, coloured by means of oxide of copper; and in the last example it will be seen that sulphate of the oxide of copper entirely opposed the transmission of the calorific rays.

The subject of calorific rays will be resumed in the article on the Prism.

111. We will conclude the subject of radiation, by pointing out a few familiar facts connected with it.

In domestic economy, vessels intended to preserve liquids, &c., at a high temperature, should be formed of polished metals; because, as we have seen (96), this is the worst radiator of heat. If two tin cups (with covers) of equal capacity, the one bright, and the other covered with lamp-black, be filled with boiling water, and allowed to stand for a time in similar situations, the water in the blackened vessel will cool rapidly, while the decrease of temperature in the bright vessel will be slow. The author has obtained the following results from his own observation.

Temperature of the room 40°.

Initial temperature of the water in both cups 198°.

	Blackened cup.	*Bright cup.*
Temperature in 10 minutes	161°	171°
20 ,,	140	156
30 ,,	124	142
40 ,,	110	132
50 ,,	100	122
60 ,,	92	116
70 ,,	84	108
80 ,,	78	100
90 ,,	74	94

From this it follows, that a black tea-pot is the very worst vessel that can be adopted for the preparation of that grateful beverage, tea. A silver tea-pot, kept exceedingly bright, is best adapted to the purpose. It has been said that the introduction of a tea-pot, many years ago, made of black, unglazed earthenware, has produced a loss to the British nation of millions of money. In fact, with such a vessel, the loss of heat from the boiling water, by radiation, soon reduces its temperature below the point necessary to extract the soluble matter from the herb, so that "after the ceremony of drinking tea, the chief value was thrown away in the residual leaves." (*Donovan.*)

Fire-irons that are bright and polished, absorb scarcely any heat from the fire near which they are placed; whereas a dull, unpolished set often becomes too hot to handle.

When houses are heated by means of hot water, the conducting pipes should be polished in their transit through halls and

places not intended to be warmed, but in rooms intended to be heated, such surfaces ought to be black, in order to radiate heat more effectually.

The metal helmet and cuirass of cavalry-soldiers, and the bright armour worn in days of chivalry, are cool dresses; since the solar and other calorific rays are not absorbed, but almost entirely reflected.

It has been said that white or gray horses suffer less from heat in summer, and from cold in winter, than those of a dark colour.

Workmen frequently protect their faces from the intense heat of furnaces by wearing masks of bright tin-foil, which reflect the heating rays.

If two thermometers indicate equal temperatures, and the bulb of one be coated with lamp-black, and both be exposed to the sun, the blackened thermometer will soon indicate a very considerable increase of temperature above that of the other.

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112. Here we conclude the present section, which we have extended to a greater length than will be found necessary in the first sections of other articles; but the fact is, that scientific instruments of every description, are so much influenced by heat, that it becomes a matter of paramount importance to the student to be made well acquainted with its various effects. Other departments of this important science, besides those here treated of, will require our attention as we proceed; the due appreciation of which will greatly depend upon the attention devoted by the student to the present section.

Section II. On Thermometrical Instruments.

113. The term Thermometer is derived from two Greek words *θερμος*, heat, and *μετρον*, a measure. The thermometer indicates the varying degrees of heat and cold, by the change of bulk of a fluid substance contained within a transparent tube, attached to a graduated scale—such fluid contracting by cold and expanding by heat, as we have already explained in the First Section.

114. In the infancy of science, the instruments which the philosopher bequeathes to posterity, are necessarily rude and imperfect: but, as these are the means by which our knowledge

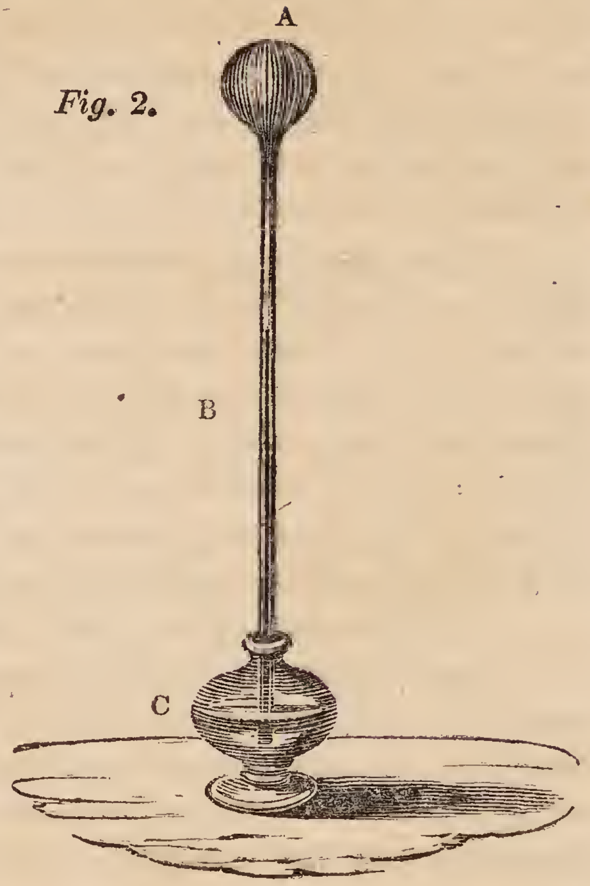
of the works of nature is acquired and improved, it follows, that the perfection of an instrument is almost coëval with that of science itself; or it may be that some happy addition to the powers of the instrument, is often the precursor of a series of novel results obtained by the master-mind which suggested a wider range of action for the instrument he employs. It would form an instructive chapter in the progressive history of the human mind, to examine the state of knowledge of the science of heat, when Sanctorio first contrived his rude thermometer: to trace its gradual improvement, as the thermometer was improved; until we arrive at our own time, when the refined and delicate Thermo-multiplier of Melloni is producing results, which must have been lost to us, had not the genius which produced them, invented the means of production, to do which all our instrumental aid was previously inadequate.

115. The first thermometer is said, by the Italians, to have been constructed by Sanctorio; and, by the Dutch, by Drebbel, about the beginning of the seventeenth century. There are numerous other claims of more or less account; but it is a futile struggle, and a vain attempt, to improve national honour, by appropriating the first rude germ of an invention, which, so far as it goes, is generally useless; since its main value is due to the successive labours of subsequent philosophers, not of one country, but of all. A scientific invention or discovery must surely have for its prime object the benefit of the whole human family, and not of one particular division of it. The French have lately made the magnificent discovery that Papin was the first contriver of a steam apparatus, bearing some rude resemblance to the modern steam-engine; and this they call *glory!* To such glory they are surely welcome; but we would suggest that the man who brought the steam-engine to its present state of perfection and power is calculated to add to the glory of his country more than the man who conceived the first crude design.

116. The thermometer of Sanctorio, or of Drebbel, is shown in fig. 2, p. 70; where A represents a glass bulb connected with a tube of the same material, open at the lower end. The air in the bulb is expanded by heat; and the open end of the tube is inserted in a liquid contained in the cup or vessel C. As the bulb cools, the enclosed air contracts; and a portion of the liquid ascends the tube, in consequence of the pressure of the atmosphere without, until the liquid enclosed by the tube equals the bulk of the air, which had been expelled by heat. Any process, tending to heat the bulb A above the temperature of the sur-

rounding air, will cause the enclosed air to expand; thereby depressing the liquid in the tube. If the temperature of the bulb A be lowered beyond that of the surrounding air, the enclosed air will contract, and more liquid will be forced into the tube. If a scale of equal parts be applied to the tube, a rough idea may be formed of the differences of temperature of bodies affecting the bulb. Instruments of this kind are called air-thermometers; because the varying elasticity of the enclosed air from heat and cold, causes the height of the liquid in the tube to vary also. This kind of instrument was also formerly called a weather-glass; because it was employed to indicate cold and warm weather. The same term is even now applied to the Barometer.

Fig. 2.



117. There are many other forms of the old air-thermometer; but as these do not vary in principle from the one just described, we need not prolong our description, except to mention an improvement by Boyle, which consisted in changing the cup C for a bottle, and closely cementing the tube B into the neck; so that a portion of air was confined in the bottle instead of in the bulb A, which was absent from Boyle's adaptation; the tube being open at both ends. The advantage of this contrivance was, that the bottle C could be inserted into liquids, and their relative temperatures compared; but Boyle found that the liquid in the tube stood at various heights, when the bottle was immersed in liquids, which had long been exposed to the same temperature. Hence he justly concluded that no dependance could be had on the open air-thermometer. Boyle's thermometer was afterwards improved by Geoffrey; but not to such an extent as to make it practically useful.

About the year 1702, M. Amoutons constructed an air-thermometer, superior to any that had yet been made; but as this instrument is now obsolete, we need not describe it.

118. The Florentine Academicians seem first to have con-

trived a thermometer, from which the influence of atmospheric pressure was removed. Their object was to get a scale with fixed points applicable to all thermometers; since it is obvious that the varying pressure of the atmosphere influenced the height of the liquid in the air-thermometer to a far greater degree than heat; and, as such, rendered the adoption of a scale with fixed points impossible.

119. Their instrument depended upon the expansion of spirits of wine, instead of air; and the mode of construction was as follows: A tube connected with a bulb, was heated so as to expel a portion of the air; and the open end of the tube was immersed in spirits of wine, which, as the bulb cooled, was forced up by atmospheric pressure into the stem and bulb. The bulb was then held downwards, and a flame applied to it, so as to boil the spirits and to purge the tube of air. While the vapour was issuing from the end of the tube, the flame of a blowpipe was applied to it, which melted the glass, and sealed it hermetically.

120. The Florentines, however, do not seem to have been very successful in the construction of their scale; principally from the want of definite and well understood points, between which degrees might be marked on the scale. No two thermometers, thus constructed, could give exactly similar indications, unless they were previously compared with, and adjusted to, each other, by the academicians themselves. The reason of which was, that the only points at which the graduation was made to begin and end were, 1st, the cold of ice and snow, for the lower limit, and 2nd, the greatest summer-heats at the town of Florence, for the superior limit; both of which are obviously uncertain, and depend chiefly upon locality. It will, therefore, be neither amusing nor profitable to the reader to dwell longer on this mode of construction.

121. On the introduction of the Florentine Thermometer into England, the first improvement of Boyle was to substitute *coloured* spirit for the *colourless* spirit, of the Italian instrument. Boyle employed cochineal to tinge his spirit; which became, as he says, of "a lively red; and 'tis pleasant to see how many inches a mild degree of heat will make the tincture ascend in the cylindrical stem of one of these useful instruments." He proposed to fix one point of the thermometric scale, by observing the height of the liquid in the stem, when the bulb was placed in thawing oil of aniseeds; a temperature which he preferred to that of melting ice, because the former was more readily procured at any time of the year. It is pro-

bable that Hooke first suggested the temperature of freezing water as one of the fixed points; and Halley proposed the boiling point of spirits as another. He also proposed the boiling of water as a fixed point. The reason why these differences of opinion, as to the adoption of a standard minimum of temperature, existed, was, that Musschenbroek, Haller, Derham, and many other philosophers believed that water did not always freeze at the same temperature: that climate, and other considerations, made the freezing point of water higher in one country than in another. Another source of difference between different philosophers was that, whereas some advocated the adoption of two standard points between which the graduation should be effected; others, among whom were Boyle and Hooke, contented themselves with one point (the lowest) of temperature, and graduated upwards by 10,000ths, as high as they conceived to be necessary.

122. Halley's first idea of a standard of temperature was derived from the constancy which had been observed in the temperature of the caverns under the Observatory at Paris, from which he proposed the temperature of deep pits as likely to furnish a standard. This, however, was an impracticable project, and he soon directed his attention to the phenomena connected with the boiling of alcohol, water, and mercury; and fancied that he perceived the boiling point of alcohol to be more constant than those of the other two liquids. This has been abundantly proved, however, to be incorrect; as the strength of the spirit greatly influences the rapidity of its vaporization.

123. As spirit boils at a comparatively low temperature, thermometer-tubes, filled with it, frequently burst when exposed to a temperature beyond their boiling points. To remedy this inconvenience, and also to obtain a wider range of temperature than could be indicated by a spirit-thermometer, Newton employed linseed-oil as a substitute; on account of the capability which it possesses of bearing a low temperature without freezing, and a high temperature without vaporization. This substance is however slower in its motions than spirit, and adheres, to an inconvenient extent, to the inside of the tube; and although its boiling point is 600°, yet its fluidity is various at different temperatures. This fluid is therefore, on many accounts, objectionable. The combined efforts of Boyle and Newton, however, brought the graduation of the oil-thermometer to greater perfection than had previously been reached with the air and spirit-thermometers. Boyle supposed the interval between the

temperature of melting snow and the common temperature of the human body, to be divided into twelve equal parts; and he compared these parts with the indications of the oil-thermometer, thus:—he called the whole mass of oil, when at the temperature of melting snow, 10,000; and, by careful experiments, he found that, at the temperature of the human body, the bulk was 10,256; at that of boiling water, 10,725; and at that of melting tin, 11,516. By multiplying the excess of bulk for boiling water (725) by 12, and dividing by the excess of bulk for the temperature of the human body (256), he obtained the number 34; which was indicative of the boiling point of water. The tenacious quality of the oil, however, as we just now observed, deprived this instrument of all its practical value.

124. The most decided improvement however was the adoption of mercury, enclosed in a bulb and tube purged of air. Halley conceived the idea of employing mercury; but he rejected it on account of the small amount of its expansibility, which he estimated at $\frac{1}{74}$ from freezing to boiling water. But it has since been found to be $\frac{1}{55.5}$. The merit of putting this improvement into practice is however said to belong to the astronomer Roëmer; as also the no less important invention of the scale known as Fahrenheit's. Early in the eighteenth century, thermometers constructed by Daniel Gabriel Fahrenheit, a native of Dantzic, residing at Amsterdam, were known over Europe.

125. With this brief sketch of the history of the common thermometer, we pass over the minor improvements, which experience has suggested from time to time, to a description of the construction of the instrument; and as this will occupy by far the most important and considerable part of the present section, the brevity of our historical details may, perhaps, be excused. We propose therefore to state, 1st, the methods of filling a mercurial thermometer, and the precautions necessary to be attended to in the operation: 2nd, the plan of construction of the various thermometric scales in common use.

126. We will first, however, briefly remark, that the advantages of using mercury as the thermometric fluid, may be considered as of four kinds:—1. It is found to enlarge its bulk more equably for equal increments of heat, than most other bodies. 2. It is more easily freed from air than either alcohol or oil; a quality of much importance in the construction of these instruments. 3. It has a very convenient range; for, while oil becomes viscid and very tenacious at low tempera-

tures, and alcohol boils before we can attain a high temperature, mercury will retain its liquidity unimpaired for a range of more than 700°. 4. It accommodates itself more speedily to the temperature of surrounding bodies than many other liquids. We stated, in the first section (67), that a less quantity of heat is necessary to raise a given quantity of mercury to a certain temperature, than is necessary to raise an equal quantity of water to the same temperature; and this is the same thing in effect, as to say that mercury becomes heated more speedily than water. This property results likewise from the circumstance that mercury, being a metal, conducts heat from one particle to another more rapidly than water, or any other liquid.

127. In the comparison of scientific results at different times and in different places, it is obviously necessary to adopt some standard of universal reference; and as, in the case of the common thermometer, pure mercury is the standard, it will be interesting to give a brief account of this metal, and of the methods by which it is purified.

128. Mercury was known to the ancients. As it often occurs in a native state, it was not unlikely, at a very early period, to attract general notice. Its colour is white, and similar to that of silver. Hence the name *hydrargyrum*, water-silver; a compound from the Greek ὕδωρ, water, and ἄργυρος, silver; *argentum vivum*, quick, or living silver; the term *vivum*, or *quick*, signifying *alive**. It is distinguished from all other metals by being fluid at common temperatures.

129. The principal mines in Europe, from which it is obtained, are at Idria in Carniola; and at Almaden in Spain. It is somewhat scarce; and occurs in nature in only five different states, constituting five different species of mercurial ore. Native mercury occurs in fluid globules in most of the mines which produce the ore. The most abundant ore of mercury is *cinnabar*, a sulphuret of mercury.

130. The process of smelting is very simple. Cinnabar is mixed with half its weight of lime, or of iron filings, and distilled in an iron retort, or a kind of oven constructed for the purpose. The sulphur is abstracted by the lime or iron; and the mercury being converted into vapour, is made to pass over into cold water, where it is condensed into pure mercury. It is packed in iron bottles, and so exported.

131. Mercury, however, as it is sold in England, is fre-

* The most original meaning of *quick* (an old Saxon word) is *living* in which sense it is most usually understood in Scriptural phraseology.

quently adulterated with other metals, so as to render it quite unfit for the purposes of the thermometer. It combines with great facility with lead, tin, and bismuth; and these are the common adulterants. It may be purified by agitating small portions of it in a glass bottle containing sand or pounded loaf-sugar, opening the bottle from time to time, and blowing out the impure air by means of bellows. It may then be filtered through a funnel of clean writing-paper, or strained through chamois leather. By these means, the impurities will, to a great extent, be removed.

132. But it is, perhaps, more satisfactory to distil the metal. For this purpose, let the metal be placed in a close iron or earthenware vessel, at the top of which is a tube to be conducted into a receiver, which must be kept cool during the whole operation. As mercury boils at a lower temperature than any other metal, it will soon be converted into vapour; and the other metals and impurities with which it is mixed, will remain behind in a liquid or solid state. If, however, the mercury be combined with any liquid which boils at a lower temperature than mercury, such liquid will first be vaporized, and may be condensed in a separate vessel.

133. Pure mercury has neither taste nor smell; its surface makes an excellent mirror; indeed, common glass mirrors are coated with mercury spread upon tinfoil, with which it forms a solid amalgam. The specific gravity is 13·568 at 60°. It boils at 656°. Its vapour is invisible and elastic, like that of water; and the elasticity of course depends on temperature. Geoffrey, at the request of an alchemist, enclosed a quantity of it in a strong iron globe, secured by iron hoops, and put the globe into a furnace. Soon after it had acquired a red heat, it burst with great violence; and the mercury was completely dissipated.

134. Having obtained pure mercury as an indispensable requisite for the construction of a common thermometer, we proceed to inquire how its contractions and expansions are observed with ease and precision, under the various changes of temperature to which it is to be exposed. For this purpose a hollow glass stem, or tube, is selected, the *calibre* or *bore* of which should be perfectly uniform throughout. Tubes of very narrow bore are termed *capillary**; at any rate, the bore does not greatly exceed the diameter of a hair, and hence such tubes are often employed. These tubes are formed by drawing out rapidly a lump of glass, while it is yet ductile under the influ-

* From the Latin *capillus*, a hair; the diameter of such tube being only, as it were, a *hair's-breadth*.

ence of heat. A small hole is first pierced through the glass; and this is the bore of the tube, which continues during the process of drawing, and would still exist, although the tube were drawn to the finest thread. As the scale attached to the thermometer is a scale of equal parts, it is necessary that the bore of the tube be of precisely the same diameter throughout. But, in fact, the tubes, as obtained from the glass-houses, are generally *frusta** of very elongated hollow cones; which by extension become more or less perfectly cylindrical. If one part of the bore be larger than another, a division at that part would belong to a greater change in the volume of the mercury than a division at the other part, where the diameter is less. A very simple mode has been devised by Gay-Lussac, for determining the value of tubes intended to be employed in the construction of thermometers. A drop of mercury is introduced into the bore, so as to occupy a space within it of not more than a quarter of an inch. This mercury is to be gradually moved through the tube from one end to the other, and made to remain stationary at different parts by holding the tube horizontally; and the space which it occupies in the tube at different places, is to be carefully measured by a pair of compasses, or an accurate scale. If the mercury occupy the same length in every part of its bore, then such bore is manifestly uniform throughout its length; but if it occupy a less extent at one part than at another, there must be a variation in diameter; and not being perfectly cylindrical throughout, such a tube cannot furnish accurate results when employed in the construction of a thermometer. So rigid is this test, that it is computed, that not more than one thermometer-tube in six is found to be quite accurate.

135. The bore of the thermometer-tubes is sometimes elliptical. The advantage gained by this form is, that a very small column of mercury is more visible, when expanded at right angles to the line of vision. But it is difficult to ensure accuracy in tubes of this kind.

136. Supposing, then, the tube to be chosen with due precaution, a bulb must be blown at one end to serve as a reservoir for the mercury. The usual method of doing this is to heat one end of the tube until it is closed, and the glass has become soft, and then to expand it by blowing air into it at the other end. This should not be done by the mouth, since moisture will thus be introduced into the tube, the subsequent effect

* A frustum is a portion of some solid separated from the rest. The frustum of a cone is the part remaining when the top is cut off by a plane parallel with the base. Sometimes it is called a *truncated* cone.

of which will be baneful; as it will mix with the mercury, and expand with it in different degrees; and so the observed result will be erroneous, depending partly upon the expansion of the mercury, and partly upon that of aqueous vapour. It is, therefore, usual to tie a bag of caoutchouc, filled with dry air, to one end of the tube, to heat the other end, and then to press air from the bag, along the tube; which air will expand the glass into a bulbous form of any desired size.

137. The size of the bulb will depend upon the purposes to which the thermometer is to be applied; but it is found that the larger the bulb is in proportion to the stem, so much the more sensible will be the thermometer to the changes of temperature. As the pressure of the air acts more equally upon a spherical, than upon a cylindrical or *pyriform** body, the first is preferred; but when the bulb is very large in proportion to the stem, one of the two latter is adopted. With bulbs of large size containing mercury, a slight pressure of the hand, apart from its natural heat, causes the mercury to rise in the stem; so that this is a reason why the bulbs should be limited in size, in order that the source of error, arising from varying atmospheric density, should be diminished.

138. In order to fill the bulb with mercury, much precaution is necessary. If the bore of the tube be wide, there is no difficulty; but as most tubes are capillary, the matter is not so easily effected. In the former case, the mercury need only be poured through the stem into the bulb;—the method in the second case depends upon the expansive force of atmospheric air, as also upon its pressure. The bulb is held in the flame of a spirit-lamp, so that the enclosed air, by being heated, expands; and thus a large portion is expelled. The tube is then inverted, and its open end plunged into pure mercury. The heat, which rarefied the enclosed air, being removed, such air cools, and in cooling, regains its former elasticity; but its bulk at its former temperature is greatly diminished. This, however, is compensated by the entrance of mercury, which is forced into the tube by atmospheric pressure; and a portion also of the mercury will be found to have entered the bulb. Mr. Nicholson recommends, that instead of inverting the tube, it be kept as much as possible in a horizontal position, and the open end simply dipped under the surface of the mercury. The process being conducted thus far, heat is to be again applied to the bulb, and the mercury is to be boiled. The vapour of the mercury will expel all the air; so that the bulb and stem will be entirely filled with mercury

* Having the shape of a pear; from the Latin *pyrum*, a *pear*.

and its vapour. When the flame is removed, the vapour will gradually be condensed into the liquid form, and the tube and bulb will be entirely filled with pure mercury alone.

139. It is sometimes usual to boil the mercury in the bulb and tube, in the following manner. A slip of clean writing-paper is rolled round the open end of the stem, and tied in such a manner as to form a kind of cylindrical cup, capable of holding as much mercury as the bulb. A drop of mercury is placed in this cup, and a flame applied to the bulb. The vapour of mercury will soon force part of the contents of the bulb and stem into the paper vessel; and on removing the flame, this will suddenly return. The value of this operation is to ensure the absence of moisture and air from within the instrument.

140. But, as the indications of the thermometer depend upon the rise and fall of the mercury within the tube, it is obvious that the bulb, and part only of the stem, must be filled with mercury:—that, in any depression of the mercury by cold, there should still be a portion of the mercury in the stem to indicate its amount; and that in elevation by heat, the tube should be sufficiently long to allow the utmost range to the fluid metal; while, at the same time, no other fluid should be present above it, to counteract its ascensive force. These conditions are fulfilled by using more metal than the bulb can enclose during the greatest contraction, and less than the bulb and stem can contain during the greatest expansion of the metal, and in addition to this, by making the space above the surface of the mercury a perfect vacuum. But this latter point does not seem to be of paramount importance.

141. Another mode of filling thermometer-tubes is as follows: By means of the elastic bag of air, two bulbs instead of one, are blown, one at one end of the tube, and the other near the other end. The bulb near the one end is heated, to expel a portion of the air; and the open end just beyond it is immersed in pure mercury. As the glass cools, a portion of the metal is pressed up into that bulb. The tube is then held with the bulb at the other end downwards, and this latter bulb is heated, whereby the air is rarefied, and a portion of the mercury passes into it. In this way, this bulb at the end of the tube is entirely filled, and a portion of the mercury is left in the other bulb. The tube is now held by a piece of iron wire, attached by its two ends to the stem or tube, over a charcoal-fire, and heated, so as to vaporize part of the mercury; by which means, air and moisture are expelled. The open end is then closed with sealing-wax. The tube, being removed from the fire, is then

inclined, so that a portion of the mercury falls into the stem from the upper bulb, and is made to settle at the desired height. If too much, or too little mercury be in the lower bulb and its stem, it is easy to transfer portions of the metal to or from the other bulb, by giving an inclination on one or the other side to the stem. The flame of a blow-pipe is applied a little below the upper bulb, and the tube is permanently closed; and then detached from the upper bulb, and the portion of the tube beyond it.

142. Should this plan (which is not the usual one,) not be adopted, the tube is closed by gently heating the mercury in the bulb, until it rises to the point at which the sealing is to be made. At this point the tube is softened by a blow-pipe flame, the flame from the bulb being at the same instant removed; and the stem is thus permanently closed by melting the glass.

143. A very good test of the absence of air and moisture in the stem of a thermometer, is to invert it; if the mercury fall to the extremity of the tube, the vacuum may be considered as perfect. But if the bore of the tube be exceedingly small, capillary attraction will operate to prevent the descent of the metal.

144. We have thus far described the method of constructing one thermometer; but suppose that, instead of one, a large number had been factured, and the process of graduation were about to be commenced. If these tubes were all perfectly cylindrical, and of equal diameter one with the other, a scale of equal parts applied to them would indicate the amount of variation in the height of the mercury in the stem, in consequence of change of temperature. But this method would greatly lessen the value of the thermometer as an instrument of comparison, observation, or research; because, in practice, it would scarcely be found to apply to two, much less more, of the instruments in question. The grand object sought to be attained in the construction of scientific instruments, is an universality of application of instruments of the same kind, so that all may afford the same results under the same circumstances, and that any variation in their indications may be referred to a change of circumstances, and not to a change in the modes of their action. To effect this object, it is necessary then, that each thermometer have its own scale peculiar to itself, constructed on principles which are unerring in practice, and which we now proceed to explain.

145. If a number of thermometers, prepared as before directed, be placed in a vessel containing melting snow or ice, the mercury will sink in each stem down to a certain point, at which

it will remain stationary during the whole of the liquefaction; and so long as a portion of the snow or ice remains undissolved, the mercury will neither ascend nor descend in any of the stems. The height of the mercury in one stem may be different from that in another; no two heights may, in fact, correspond with each other; but each one will have in its stem a fixed point, peculiar to itself; the amount of depression in every case depending upon three circumstances; 1st, the temperature of melting ice or snow, which is constant; 2d, the size of the bulb compared with the stem, which may be variable in each case; 3d, the quantity of mercury enclosed in the bulb and stem, which may also be variable. A scratch is made, by means of a file, on the exterior of the stem of the instrument, exactly opposite the point at which the mercurial column terminates. This is called the freezing point, or temperature of melting ice; and it is the same all over the world, at every season of the year; neither is it influenced by the temperature of the apartment in which the graduation is conducted. It is necessary, however, that the graduation be made before the whole of the ice or snow is liquefied; for the moment that that is complete, the pure water which results, gradually increases in temperature, until it acquires the temperature of the surrounding air.

146. But another point is still wanting, in order to determine the extent of the degrees to be attached to the scale of the instrument. This is the *boiling point;* and its determination is more difficult than the freezing point; because, unlike the latter, it is in part dependant on the pressure of the atmosphere, which is subject to much variation. But, supposing the barometer to stand at the same height, then the boiling point of pure water in an open vessel, is constant all over the world. If a vessel containing pure water be heated, and the thermometer-tubes be suspended in it, the column of mercury in each tube will gradually rise in proportion as the temperature of the thermometer rises; but the moment ebullition takes place, the mercury will cease to rise; it will in fact, remain stationary, until the whole of the water is dissipated in vapour. A mark made opposite the end of the mercurial column, will therefore give the water-boiling point of the thermometer in each case; this may also be at various heights in various instruments, depending upon the circumstances which we stated as regulating the height of the mercury at the freezing points in the first graduation.

147. About the middle of the last century, a committee of seven men of science was appointed by the Royal Society, to inquire into the principles which regulate the construction of

the thermometer. Their report contains much valuable information; some of which we proceed to lay before the reader. They recommend that the boiling point be fixed, when the barometer stands at 29·80 inches; that the bulb of the thermometer be not immersed in the water; because they found that, according to the depth of this immersion, the mercury rose in the tube. They advise a vessel of tinned-iron, with an easily fitting cover, rendered steam-tight by a ring of woollen cloth between it and the vessel, to be employed as a boiler; the cover to have two apertures,—one to act as a chimney, with an area of not less than half a square inch, and about three inches high, to convey away the steam of the boiling water: and the other hole for a cork, through which the thermometer-stem is to pass in such a manner that the bulb shall not touch the surface of the water, but be surrounded with steam; no more of the steam is to be exposed above the cork, than is necessary to show the height of the mercury when the water is boiling briskly. When matters are thus adjusted, a thin plate of metal is to be placed over the chimney, to prevent the escape of the steam as it is formed; the bottom of the boiler is heated, and when the mercury has risen to the temperature of the steam, it is to be allowed to remain at rest for a few minutes, and then its height to be accurately marked with a file on the outside of the tube.

148. In the absence of such contrivances, it has been recommended to wrap several folds of linen or flannel round the tube, nearly as high as the supposed boiling point. The thermometer is then to be held in an ascending current of boiling rain water; the bulb to be held an inch or two below the surface; boiling water is to be poured several times over the covering of the stem at intervals; and when the water is boiling briskly, we must mark the height of the mercury in the tube.

149. To ascertain the boiling point, Dr. Ure adapts to the mouth of a tea-kettle, a cylinder of tin-plate, the top of which contains a perforated cork, through which the stem can be slid to any convenient point; while the tin cylinder may also be raised or lowered till the bulb rests an inch beneath the water. The nozzle of the kettle is stopped up with the cork; and at the top of the cylinder, a side hole is left for the escape of the steam.

150. Since it would be a great inconvenience if, in the construction of a thermometer, we had to wait for the state of the atmosphere indicated by 29·80 inches of the barometer, for fixing the boiling point, a table of corrections has been con-

structed for every ordinary variation of atmospheric pressure; by means of which the height of the barometer can be corrected to the standard height.

The first column contains various heights of the barometer, at which the boiling point may take place, when the thermometer is immersed in steam; and the second column when it is immersed in water. The third column contains corrections in 1000ths of the interval between the freezing and boiling points of water.

Steam.	Water.	Correction.	
	30·60	10	
	·50	9	
30·71	·41	8	
·50	·29	7	
·48	·18	6	
·37	·07	5	Lower.
·25	·95	4	
·14	·84	3	
·03	·73	2	
29·91	·61	1	
·80	·50	0	
29·69	29·39	1	
·58	·28	2	
·47	·17	3	
·36	·06	4	
·25	28·95	5	
·14	·84	6	Higher.
·03	·73	7	
28·92	·62	8	
·81	·51	9	
·70		10	
·59			

151. In the construction of the foregoing table it is supposed that the thermometer-tube is cylindrical, and of equal dimensions throughout.

152. It has been observed, that mercurial thermometers slowly change their point of zero; which becomes uniformly higher than at the time of graduation. This change is said to be owing to a diminished capacity of the bulb, due to the atmospheric pressure constantly exerted on its exterior, and not counterbalanced by any pressure from within. This phenomenon has not been observed in thermometers which are unsealed, or in those containing alcohol. In the latter case, a vacuum cannot exist within the tube; the space above the liquid column being saturated at all times with vapour of alcohol. The principal contraction of mercurial thermometers takes place soon after the tube is sealed; and on this account some

months should be permitted to elapse between the sealing and the graduation of a thermometer. Although the cause of this deviation is generally supposed to be such as we have just stated, yet there are many distinguished names opposed to this opinion; among which is that of Arago, who thinks that any change of height in the mercury is due to the escape of particles of air from between the mercury and the glass; and Bellani has attributed it to molecular action in the particles of the glass; meaning thereby, that a considerable time elapses before the particles assume their final positions after the bulb is blown.

153. Having fixed the two important points; those of *freezing* and *boiling* water; the interval between the two must, of course, include that portion of the tube, which corresponds to the expansion of the mercury between these two temperatures; and since this expansion is constant, it follows that the proportion, which the capacity of the tube between these two points bears to the volume of mercury included in it at the temperature of melting ice, must be constant also. The capacity also of the tube between the above points, will always be proportionate to the capacities of the stem and bulb below the freezing point. This is a consequence of the uniform expansion of mercury, when subjected to the same limits of temperature. Now, between the boiling and freezing points of water, the expansion of mercury amounts to $\frac{1}{63}$rd part of the volume which it occupies at the temperature of melting ice: therefore the capacity of the tube, between the two fixed points must always be equal to $\frac{1}{63}$rd part of the capacity of the bulb, together with that portion of the stem below the freezing point. The varying lengths, therefore, of the intervals between the two fixed points in different thermometers, will be found to arise from the different proportions, which the capacity of the bulb and stem below the freezing point, bears to the interval between the freezing and boiling points.

154. A plan is sometimes adopted in warm climates,—where ice and snow cannot be conveniently procured,—of graduating the thermometer by means of the boiling point alone. For this purpose, the stem is graduated by means of a drop of mercury of a known weight, which is moved about in various parts of the tube, as before described (134); a bulb is then blown upon one end of the stem, and mercury is inserted in the usual manner, the quantity of which is accurately weighed; and since the space between 32° and 212° corresponds to a mercurial expansion of $\frac{1}{63}$rd, the number of graduated spaces between the boiling and the freezing points may be computed. Thus,

suppose the weight of the included mercury to be 378 grains: then $\frac{1}{63}$ of that quantity, or 6 grains, corresponds to 180° of Fahrenheit. If the initial measuring column were 0·6 of a grain, then ten of those spaces would comprehend the range between freezing and boiling water. Hence, if we know the boiling point, we can set off the freezing point; and divide each space successively occupied by the drop of mercury into 18 equal parts, or degrees of Fahrenheit.

155. The thermometer, when graduated, is firmly attached to a frame of hard dry wood,—such as boxwood, or of metal. Opposite to the freezing and boiling points, a line is cut or engraven; and the space between the two is divided, in this country, into 180 equal parts, called *degrees;* the extent of each degree depending of course upon the extent of the interval between the boiling and freezing points. These degrees are continued above and below the two fixed points,—the numeration commencing 32° below the freezing point, and reckoning upwards; so that the boiling point is 212°. This is Fahrenheit's scale. By mixing salt and snow he sank the thermometer to a low point,—to a point, in fact, which he erroneously thought to be the greatest cold that could be produced: and with this impression, he commenced his scale from such point, which he called zero, or 0°; between this temperature and melting ice, he marked 32°, and by continuing to divide his scale equally, he arrived at the 212th, which he found to be the boiling point. But, as there are numerous temperatures far below zero, it has been found necessary still to continue the scale downwards; and the number of degrees below zero has prefixed to it the negative sign, $-$; while the number of degrees above zero has for a prefix, the positive sign, $+$. Thus $-12°$, signifies 12° below zero; and $+15°$ implies 15° above zero.

156. Fahrenheit's scale is not used in France. Before the Revolution, Reaumur's scale was adopted; and it it is still used in some parts of Europe. The liquid employed in Reaumur's thermometer, was spirits of wine; but De Luc substituted mercury. The fixed points on this scale, were the same as on Fahrenheit's; but the numeration commenced from the freezing point, which was zero. The interval between the two fixed points, was divided into 80 equal parts; so that the boiling point was 80°; and a degree on this scale was longer than one on Fahrenheit's, in the proportion of $2\frac{1}{4}$ to 1. To convert a temperature indicated by one of Reaumur's instruments, to a corresponding temperature on Fahrenheit's, it is necessary to multiply the degrees upon Reaumur's by $2\frac{1}{4}$, and to add to the

product 32°, in order to allow for the distance of the points at which the scale commences. To reduce a degree of Fahrenheit to one of Reaumur, 32° must be subtracted, and the remainder diminished in the proportion of $2\frac{1}{4}$ to 1.

157. In 1742, Celsius, Professor of Astronomy at the University of Upsal, in Sweden, published an account of a new thermometer, the scale of which commenced, like that of Reaumur, at the freezing point of water; and the interval between that and the boiling points he divided into 100°. This thermometer was adopted by the French during the Revolution under the name of *Thermomètre Centigrade*; and the reason for it was, that the centigrade scale harmonized with their decimal system of weights and measures; which will be explained in our article on the Vernier (9). It is now in general use in France, and in several other parts of Europe. Every one of its degrees is equal to $1\frac{4}{5}$ of a degree of Fahrenheit; or 100° of the former are equal to 180° of the latter. To convert a temperature observed on Centigrade to the corresponding temperature, as indicated by Fahrenheit, it is necessary to increase the number of degrees in the proportion of 100 to 180, (which is the same as 5 is to 9), and to add to the result 32°, as in the case of Reaumur's scale, in order to allow for the differences at which the scale begins. To reduce a degree of Fahrenheit to one of Centigrade, 32° must be subtracted, and the remainder diminished in the proportion of 9 to 5.

158. The French astronomer, Delisle, who was invited to St. Petersburgh by the empress Catherine the First, constructed a thermometer during his residence in that capital, between 1726 and 1748. This instrument has been adopted by the Russians, and is known by the name of its inventor. In Delisle's scale the numeration begins at the boiling point of water; which is considered as the boundary between heat and cold. The numbers from that point increase downwards, and therefore indicate contraction instead of expansion. The boiling point of water is zero, and the freezing point 150°. Moreover 5° of Delisle are equal to 6° of Fahrenheit; so that to convert the degrees of the former into those of the latter, we must multiply by 1·2, and subtract the product from 212, if the temperature be below boiling water; but add the product to 212°, if the temperature be above that point.

159. Another scale was proposed by Dr. Murray, which seems in many respects to be desirable. It was suggested that in this the two extreme points should be the freezing and boiling points of mercury; that is, $-39°$ and $+661°$ of Fahren-

heit, and that the interval be divided into 1000 parts. On this scale, the freezing point of water would be about the 100th degree, and the boiling point would be at 357°, and each degree would be to one of Fahrenheit's, as seven to ten. It was to be called the *Millegrade Scale.* Although numbered in relation to mercury, it was to be graduated in the usual way, by means of freezing and boiling water. The advantage sought for in this scale was the simplicity of the centigrade scale; the smallness of the degrees, which would obviate the necessity of fractional parts; and the consideration that negative degrees would be superseded.

160. It is a matter of regret that philosophers should adopt scales of such various indications, in different countries. One scale common to every thermometer in every part of the world, would enable us to be more certain of precision in the observed results of others; and at the same time would tend to show that the harmonies existing in nature, ought to be, as far as possible, imitated by her students, in their mutual intercourse.

161. We have already explained, in the first section, (36,) the difference between the degrees of temperature observed by means of the thermometer, and the actual quantity of heat contained in a body by which the thermometer is affected. The reader will, therefore, be aware that although two substances may indicate the same temperature by the thermometer, yet the amount of caloric in one may greatly exceed that in the other. When two dissimilar bodies are heated to the same temperature they do not each receive the same increase of heat; but they experience such a change, that the mercury in a thermometer exposed to them undergoes, in each case, the same amount of expansion. The indication of a thermometer is an *effect*, not a *cause;* and by this effect we estimate the value of other effects, which, together with the thermometer itself, are due to the same cause. The reader will not err if he clearly distinguish between the terms *measurer of temperature*, which the thermometer really is, and *measurer of heat*, which it is called, but which it is not. Science affords no instrument completely answering to this latter term.

162. We have hitherto spoken of the expansion and contraction of the mercury alone, in the thermometer, as a measurer of temperature; but there is another substance, upon whose varying expansion and contraction the height of the mercurial column to a certain extent depends. This is the glass *bulb* and *stem*, in which the mercury is contained. Yet it happens, fortunately, that under all the variations of temperature to which

a mercurial-thermometer can be subjected, the expansion of glass is in proportion to that of mercury; and therefore, the change of volume in the mercury, bears a constant proportion to the change of capacity in the glass tube. It follows from this, that the variation in the height of the mercurial column must bear the same proportion to the variations which it would experience, if the glass were not subject to expansion or contraction. If the mercury and the glass expanded *equally* with equal changes of temperature, then it is clear that the mercurial column would never appear to rise or fall at all; but would always be stationary. But as the change in bulk of the glass bears a very small, (though constant,) proportion, to the change in bulk of the mercury, the expansion of the former does not afford space for the increased volume of the latter; and the mercury, therefore, is forced up the tube; or *vice versâ.* Hence the variation of the mercurial column arises from the difference of expansion between the mercury and the glass; and this difference, from the freezing up to the boiling point, amounts to $\frac{1}{63}$rd part of the volume of mercury at 32°.

163. Different kinds of glass expand in different proportions; but all expand proportionably to each other, and to mercury:—and, as during the graduation of the thermometer at the freezing and boiling points, the glass is affected in a manner which is not subject to change in the subsequent practical application of the instrument, it follows that the indications of the mercurial column may be regarded without any reference whatever to the change of bulk of the glass, in which the mercruy is contained.

We have said (126,) that the expansion of the mercury between 32° and 212° is nearly equal for equal increments of heat. Above this (according to Dulong and Petit), the increasing rate of the expansion of mercury becomes sensible, by exposing a mercurial and an air-thermometer to the same temperature; taking care to correct the instruments for the expansion of glass. The following table exhibits the points on the two scales, resulting from the same temperatures.

Air Thermo.	Mercurial Thermo.	Difference.
212°	212°	0°
299·66	302	2·33
386·69	392	5·31
473·09	482	8·91
558·86	572	13·14
662	680	18

164. Thus it appears that the boiling point of mercury, as

measured by its own expansions, is 680°; but by the expansion of air, 662°. If a common thermometer be plunged into boiling mercury, it stands, (according to Crichton,) at 660°: so that the expansion of the glass is equivalent to 20°; and almost exactly counteracts the increase of the rate of expansion of the mercury. "The consequence," as Dr. Thomson says, "of this fortunate coincidence is, that an accurately graduated mercurial glass-thermometer is an accurate measurer of the increase of temperature, as high as the boiling point of mercury, or to 662°."

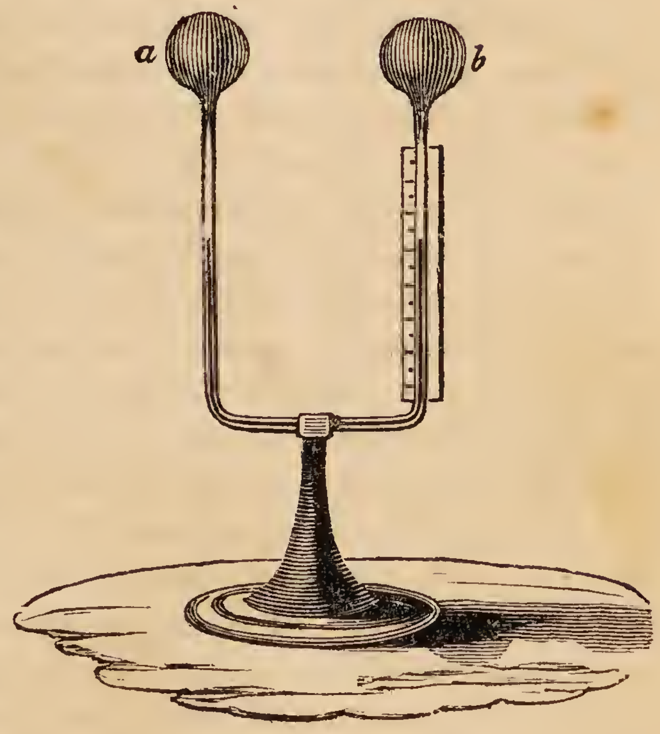
165. Since below the freezing point of mercury, and above its boiling point, temperatures cannot be estimated by the mercurial-thermometer, other means have been sought to estimate the temperatures, at which many processes in science and in the arts are conducted. The means for estimating low degrees of cold are sufficiently simple. A liquid is chosen which does not congeal by any reduction of temperature that we can either command or observe in nature:—such a liquid is *alcohol*. It is obvious that the expansion of this liquid, when uniform, may be made to correspond to the degrees on the mercurial thermometer; and for low temperatures its indications may be relied on; in which respect it has an advantage over every other fluid: but, as it approaches its boiling point, which is 176°, its expansion is by no means uniform; indeed it cannot be safely trusted to above 100° Fahrenheit.

166. For estimating high degrees of temperature, an air-thermometer is sometimes employed. Dry air increases in volume $\frac{3}{8}$ths for every 180°, and since its progressive rate of expansion is nearly uniform for equal increments of heat, an instrument has been constructed thus:—A bulb or cylinder with a tube of platinum is formed, similar in shape to that of the common thermometer; and connected with the extremity of the stem or tube, at right angles, is a glass tube of uniform bore, filled with mercury, and terminating below in a recurved bulb. The glass tube is graduated into a series of spaces, each equivalent to $\frac{3}{8}$ths of the total volume of the platinum bulb or cylinder, with $\frac{3}{4}$ths of its stem. The other fourth is supposed to be much influenced by the source of heat. The platinum bulb or cylinder and $\frac{2}{3}$rds of its stem is to be plunged into a furnace; and the depression of the mercury by the heated and expanded air, will indicate the degree of temperature. As the movement of the column is very considerable, corrections for pressure, &c., are not made. We are not aware that this instrument has ever been applied practically.

167. The differential thermometer of Leslie is a useful and

delicate instrument, which has been applied with much success in investigating some of the laws of radiant heat. It is represented in the following figure.

Fig. 3.



It consists of a glass tube, bent into the form of the letter U, with a glass bulb containing air at each extremity, *a*, *b*. It is mounted on a stand, and a scale is connected with one of its stems. A portion of strong sulphuric acid, tinged red with carmine, occupies one stem, *a*, the curved and horizontal parts at the bottom, and part of the stem, *b*, to which the scale is attached. The latter is on the principle of millesimal degrees; and 10° on this scale are equal to 1° on the scale of Celsius.

168. When, exposed, so that both the balls are of the same temperature, the liquid remains stationary, its highest point coinciding with zero on the scale; but if one of the balls be exposed to a higher temperature than the other, the expansion of the air in the heated bulb sets the fluid in motion. The bulb *b* should be employed; because to this bulb and stem the scale is attached, and the numeration of the degrees proceeds downwards. This bulb *b* is called the *sentient* bulb, and the rise of the liquid in the other stem, indicates the *difference* of elasticity of the air in both bulbs; hence the name of the instrument.

169. Since atmospheric air, and gases expand $\frac{1}{480}$th of their whole bulk (at 32°), for every degree of Fahrenheit, the indications of this instrument are nearly correct: it owes a great part of its value to its insensibility to all changes of temperature which equally affect both bulbs; and, as it is often constructed with the sentient bulb elevated considerably above the other bulb, it is well adapted to measure the effects of radiant heat.

The bore of the stem of this instrument exceeds that of a capillary tube; and the surface of the liquid is concave, in consequence of capillary attraction.

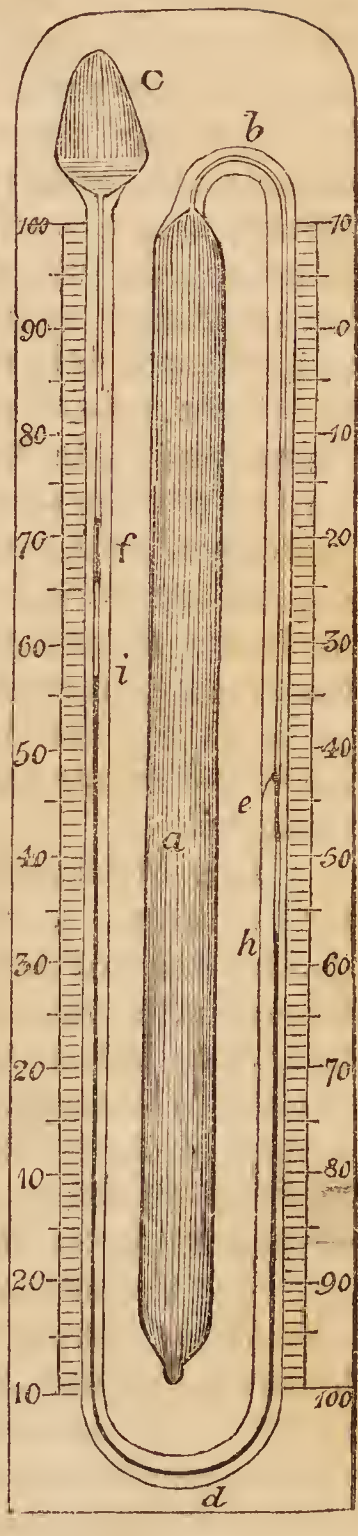
170. Thermometers of peculiar construction have been

invented for marking the highest and lowest degrees of temperature which may occur in the absence of the observer. Such instruments are called Register-Thermometers. One of these arrangements we will now describe. It is known by the name of the Day and Night-Thermometer of Dr. John Rutherford; and consists of a mercurial, and a spirit-thermometer, each provided with its own scale. The stems are placed horizontally, or at an angle inclining a few degrees upwards; and the bulbs are placed at right angles to the stems. Both thermometers are mounted on the same frame, which is made of boxwood, or ivory. To register the highest temperature between the times of observation, a piece of steel (such as a fragment of a sewing-needle), is placed within the stem of the mercurial thermometer; and, as the mercury expands, it pushes this piece of steel before it: but if after this, the mercury fall, the steel is left behind to mark the point of greatest expansion. To register the lowest temperature, a cylinder of white enamel with a small knob at each end is enclosed in the stem of the spirit-thermometer: when the spirit is contracted by cold, the attraction between the last film of the column of spirit and the enamel is sufficient to overcome the slight friction of the latter on the inside of the tube, and to carry it backwards in the direction of the bulb; but if the spirit begin again to expand, it passes the enamel without pushing it forward; and the lowest degree of temperature is thus indicated. To adjust the instrument for a fresh observation, it must be inclined, so as to bring the register-marks to the respected surfaces of the two fluids: should there be any difficulty in this, which there is not in a well made instrument, we recommend that the head of the enamel, farthest from the spirit, be made of steel; and then both thermometers may be adjusted by means of a small magnet applied to the outside of the stems. This plan would prevent the chance of fracture and other disturbances; as the instrument might then always be fixed in one convenient place.

171. In 1782 Mr. Six constructed a self-registering Thermometer, which he described in the Philosophical Transactions. It has received some modifications since his time, of which the following is a recent one:—*a*, fiig. 4. is a tube or a long bulb, filled with alcohol; and connected by a bend *b* with a tube *b d*, which is likewise filled with alcohol down to the point *h*. At this latter point, mercury commences, which is continued round the bend *d* to the point *i*, where alcohol again commences, and continues up to the top, partly filling the bulb *c*; a portion of which is left empty, to allow room for the

expansion of the liquid. Two indices, *e* and *f*, are immersed in the alcohol just above the surface of the mercury in the two exterior tubes. These indices are made of steel, coated with glass, and are terminated at each end with a spot of enamel. To prevent them from moving through the alcohol by their own weight, a spring of glass is attached to them; which, by being somewhat bent, presses lightly against the interior of the tube: these springs are sometimes made of bristle.

Fig. 4.



172. If now the highest and lowest temperatures, which occur during the absence of the observer, be required, he first adjusts the instrument, by drawing down the indices to the two surfaces of the mercury, by means of a magnet. Suppose then that the temperature increases during the absence of the observer: the alcohol in the bulb *a* expands, and presses down the mercury at *h*, which of course occasions a rise at *i*, and by that rise the index *f* is raised. Any subsequent depression of temperature will lower the surface *i*, but cannot lower the index *f*, because it clings to the sides of the tube. The greatest increase of temperature during the observer's absence is denoted by the position of the index *f*; and a scale of degrees attached to the instrument measures that change. But if the temperature fall, the alcohol contracts; and the mercury rises at *h*, pushing the index *e* before it; from which position it likewise cannot again recede, however much the temperature may afterwards increase. A scale measures that change of position as before. The application of a magnet will again prepare the instrument for another observation.

173. Another Registering Thermometer has been proposed by Mr. Forbes. It is an improvement on one, which was constructed some years ago by Lord C. Cavendish, and consists of a bulb nearly filled with spirit; the lower part containing a

little mercury. In the upper part of this bulb which is peculiarly shaped, a capillary tube terminates. This tube is bent into the siphon-form, and is filled to about half its height with mercury; above which is a column of spirit, reaching nearly to the top of the tube. When an observation on temperature is made, the indications are noticed at the point of junction of the mercury and alcohol as usual. But if, in the absence of the observer, a rise of temperature takes place, it is known thus:—the expanding mercury forces the alcohol up to the top of the tube, where it falls to the lower part of the cup which is at the top of the tube and from which it cannot escape, when the temperature again falls. The quantity of vacant space observable at the upper part of the tube, will indicate how much alcohol has passed into the cup, and how much the mercury has been raised during the absence of the observer. Thus the maximum temperature is known. To determine the lowest temperature, the other portion of the tube, being filled with spirit, at any observation, indicates the quantity of mercury which had escaped into the lower bulb at the time of the lowest temperature.

174. Mr. Kewley some years since devised a Balance-Thermometer. A tube is connected at each end with a bulb, which turns upwards. In the upper part of one bulb, is inserted the end of another tube, parallel to the former. The lower tube, and half of each bulb, are filled with mercury, the remainder of the apparatus being filled with alcohol. The whole is suspended or balanced from a frame by a central point, to which knife-edges are adjusted. When, by a rise of temperature, the alcohol in the upper tube is expanded, it will force a portion of the mercury from the connecting bulb along the lower tube to the other bulb; which is, by these means, made to descend; and the amount of that descent may be measured by the divisions on a brass scale attached to the instrument, by which angular degrees of inclination are indicated, until the balance is restored.

175. Dr. Cummings, of Chester, proposed a thermometer, which should open and shut the door, or window, of a hot-house, or other apartment, when the temperature had attained a certain point. It consisted of a large glass or iron matrass, filled with air, but containing mercury in its stem, which was inverted into a cistern containing the same fluid. The matrass was connected by a cord with the sash of a window; the cord passed over a pulley; and the weight of the matrass was so adjusted that it nearly balanced the weight of the sash. When the

increase of temperature expanded the air in the matrass, a portion of the mercury was driven out of the stem; so that the matrass became lighter than before, and therefore not an equal balance for the window-sash; which was thus let down from the top; and so a communication with the external air could be either established or cut off, according as the temperature of the room affected the air in the matrass.

176. The following modification of the mercurial thermometer was proposed by Baron Fourier in 1828. The bulb and tube are filled with mercury as usual. The bulb is surrounded with mercury contained in a receptacle, of which the sides are fixed; but the bottom is of flexible leather. This thermometer is to be employed for measuring the conducting powers of bodies. The bag is therefore rested on the substance to be examined; and the time of the descent of the temperature from a certain point to which it has been artificially raised, to the temperature of the substance, expresses, inversely, the conducting power of the substance.

177. Sir D. Brewster has applied the doctrine of the polarization of light to the construction of a thermometer. The principle on which it is constructed cannot be well understood until that doctrine be familiar to the reader. We may, however, briefly describe the nature of its indications. A piece of glass receives the property of polarizing light in the process of being heated at a candle. This polarization is the separation of a ray of light into two rays, which have different properties from each other, among which properties is that of *colour;* although the original ray may be colourless. If a circular plate of glass be heated gradually from the circumference to the centre, a ray of polarized light will elicit a series of coloured rings round the centre of the plate; so long as the glass is of different temperatures at different points. If the edge of a square piece of glass be placed upon hot iron, and a ray of polarized light be passed through the glass, a system of coloured fringes will be formed, not only at the heated edge, but at the cold edge also. Sir D. Brewster found that the tints of these rings and fringes increased as the temperature increased; and he conceived the idea of applying this property to the making of a thermometer. For this purpose, he used a series of twenty plates of glass, whose length was $3\frac{1}{4}$ inches, and width, $1\frac{1}{4}$ inch, and the thickness of the whole bundle, $5\frac{1}{2}$ inches. These plates are fixed vertically in a metallic vessel; and, when heated, liquid is poured into the vessel, the lower edges of the plates become hotter than the upper, and a ray of polarized light

being passed through the bundle of plates, the coloured fringes are observed on the surfaces of the outer plates; the tints of those fringes increasing as the temperature of the liquid is higher.

178. By referring to the paper on a "Soap-bubble" (28), the reader will see the meaning of the words *colour of the 1st order*, *of the 2nd order*, &c., and will be able to understand what follows. Sir D. Brewster found that the heat of his hand applied to the edges of twenty plates produced instantly fringes with black spaces. With twelve plates he produced the yellow of the first order; and when one plate only was used, bluish white fringes with black spaces were observed. A temperature of about 80°, that of the glass being 60°, when applied to twenty plates produced a fringe, in the centre of which was a yellow of the first order, whose numerical value is 4 on the scale of colour. Hence one plate would have produced a tint corresponding to $\frac{4}{20} = 0{\cdot}20$ of the scale.

179. When one of the plates was placed upon a bar of red-hot iron, just visible in day-light, it polarized in the central fringe, the commencement of the green of the 2nd order, which corresponds to 9·35 in the scale of colours. Now the difference of the temperature answering to 0·20 was $80° - 60° = 20°$. Hence we have the proportion—

As 0·20 : 9·35 :: 20 : 935, the difference of temperature of the iron and the glass. The temperature of the iron is therefore $935 + 60 = 995°$.

We shall not extend this notice of the *Chromatic* Thermometer, as Sir D. Brewster designated it, for two reasons: 1st, it has never yet, we believe, been brought into practical application; and 2nd, a full appreciation of its principle can only result from a careful study of the difficult and delicate subject of polarization of light.

180. In 1832 Mr. Phillips submitted to the British Association at Oxford, a description of a new self-registering Thermometer; in which a speck or bubble of air, dividing the mercury into two portions, served the purpose of an index of maximum temperature. The mode in which this instrument was made, is this: The bulb and tube are filled in the common way, carefully boiled, allowed to contain the proper quantity of mercury, and sealed. The end of the tube is then melted, and instantly afterwards the bulb is plunged into the flame of a spirit-lamp. The consequence is, that the end of the tube is blown out into a spherule; in which, when cooled, the elastic fluids are so highly attenuated, as to offer no sensible resistance

to the movements of the mercury. The air-speck or bubble will now be evident; if its length, when made to enter the tube, be less than half a degree, the instrument may be considered as fit for immediate use, as soon as, by a process of refrigeration, the right position of the air-speck is obtained. If the length of the air-bubble exceed a degree or two, it may be easily diminished by first causing the separated portion of the column to pass into the empty bulb; and, secondly, returning it into the tube, after exposing the mercury in the bulb to some augmentation of temperature.

A good common thermometer may be operated on in the same way.

181. Sir J. Herschel has, within a few years, devised a thermometer, which, under the name of the Actinometer*, will, as he conceives, give a more correct indication of the absolute heating effects of the solar rays than a thermometer, as generally constructed. He objects to the indications of the latter instrument, as the means of estimating the heating power of the sun, on the ground that the variously cooling effects of surrounding objects greatly interfere with the success of such observations. He therefore proposes to consider *time* as one of the elements of the observation.

The actinometer is a very large cylindrical thermometer-bulb with a scale greatly enlarged, so as to render the smallest possible increase of temperature distinctly measurable. The scale is not divided into definite degrees, but merely into a great number of equal parts. As a very slight elevation of temperature is sufficient to expand the liquid through the whole column or tube, the bulb itself is furnished with a screw, by withdrawing which its capacity may be enlarged, and the power of reading the indications preserved. The bulb is of transparent white glass, and is filled with a deep blue liquid. Into the interior of the bulb the rays of the sun penetrate, and are absorbed at some sensible depth within; so that the liquid is heated from without, and the whole of the heating effect is brought to bear on the expansion of the liquid. To make an observation with this instrument, it is first placed in the shade for one minute, and the indication noted; then freely exposed to sunshine, for one minute, and its indication again noticed; and then a third time, set in the shade for one minute. The mean of the two indications in the shade, being subtracted from the indications in the sunshine, gives the actual amount of dilation produced by the sun's rays in *one minute*.

* From the Greek *ακτιν, a beam of the sun;* and *μετρεω, to measure.*

182. This instrument has been employed in various elevated situations by different observers, and has been found to give remarkably delicate indications: indeed it has been stated that the altitude of the sun, in a clear climate, can be determined by the actinometer with almost as much accuracy as by a sextant, by measuring the intensity of the rays at different altitudes of the sun; the heating power gradually increasing from the horizon to the zenith.

183. Dr. Marshall Hall, in the prosecution of a train of valuable inquiries into the connexion between respiration and the irritability of certain animals, found it necessary to devise the means of observing minute changes of temperature in the animals on which he experimentalized. He observes, "It was easy, by enlarging the bulb, and by selecting a tube of extremely fine calibre, to render the common thermometer capable of more minute indications. But it was impossible to carry this change beyond a certain degree, the augmented length of the instrument becoming highly inconvenient."

To obviate this difficulty, he devised an instrument, which he described in the *Philosophical Magazine* for January 1836. The relative size of the bulb, and the calibre of the tube, is such, that $\frac{1}{10}$th of a degree occupies a considerable range of distance. The entire scale consists of ten degrees. At the upper part of the tube a small bend occurs, which is also blown out into a bulb. The lower bulb and the tube are filled with mercury; a little of which is also contained in the small upper bulb. When an experiment is to be made, the mercury in the tube is to be brought into contact with the mercury in the upper bulb, by placing the instrument horizontally, with the upper bulb turned upwards, in water of a sufficiently high temperature, about 110°. The instrument, on being removed from the water and placed vertically, exhibits that height of mercury, which corresponds to a temperature of 110°; and the whole scale is so adapted as to measure from 110° to 100°; and thus enables the operator to detect minute changes of temperature in the blood of birds and other warm-blooded animals.

184. For ascertaining temperatures above the boiling point of mercury, many instruments have been constructed. These are called Pyrometers*. Their action depends upon the principle of *expansion* by elevation of temperature, as in the case of the mercurial-thermometer; but there are many difficulties in the way of pyrometers, which render their indications scarcely comparable: at any rate, the temperatures assigned by one instru-

* From the Greek πυρ, *a fire*, and μετρεω, *to measure*.

ment are often found to be different from those indicated by another. The pyrometer, however, which is most likely to afford accurate results, is that of Professor Daniell, as described by him in the *Philosophical Transactions* for 1830, Part II.

185. This instrument consists of two distinct parts: the Register A, Fig. 5, and the Scale B.

The register is a solid bar of black-lead earthenware, 8 inches long, $\frac{7}{10}$ths of an inch wide, and of the same thickness. A hole *a a′* is drilled down this, $\frac{3}{10}$ths of an inch in diameter, and $7\frac{1}{2}$ inches deep. At the top of the bar, and on the nearer side, about $\frac{6}{10}$ths of an inch in length of its substance is cut away to the depth of half the diameter of the hole. When a bar of any metal $6\frac{1}{2}$ inches long is dropped into this hole, it rests against the solid end of the bar at *b*; and a cylindrical piece of porcelain *c c′*, about $1\frac{1}{2}$ inch long, serving for the index, is placed upon the top of it, which index, being partly in and partly out of the hole in the bar, is firmly kept in its place by a band of platinum *d*, which is tightened as much as may be necessary by a small wedge *e*. "It is obvious," as Professor Daniell remarks, "that when such an arrangement is exposed to a high temperature, the metallic bar (in the hole *a a′*) will force the index (*c c′*) forward, to the amount of the excess of its expansion over that of the black-lead; and that when again cooled, it will be left at the point of greatest elongation." He does not think that the contraction, which the black-lead may suffer from the great heat, will lead to any fallacy; as the greatest expansion of the metal will have been completed at the point of time, when its earthenware case may slightly contract, and the index will still mark the point of the furthest extension.

c

Fig 5.

e

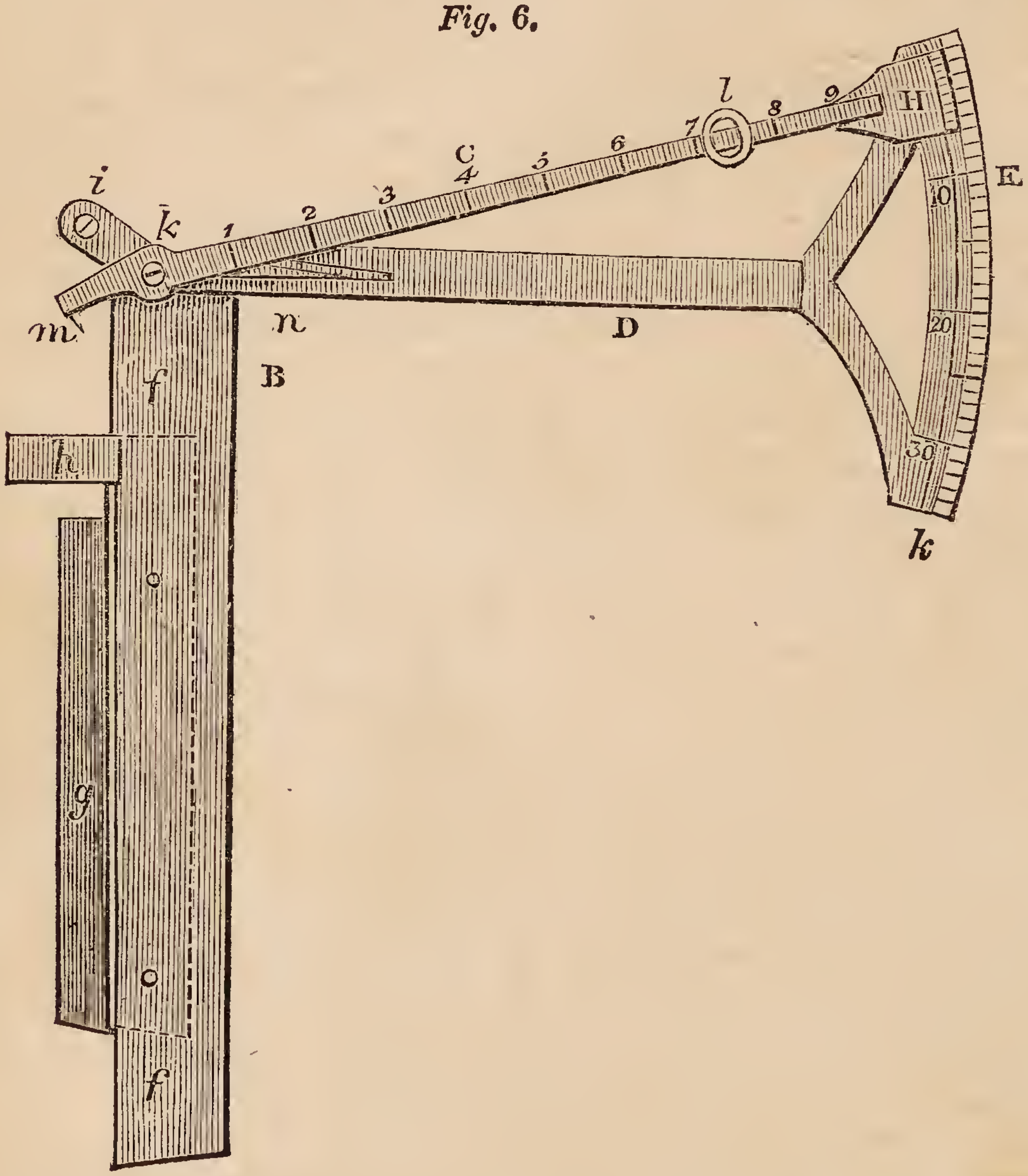
A

b

186. We now turn to the contrivance, by which the expansion of the metal is measured. The amount is in all cases very small; but it is rendered more perceptible by the apparatus here employed. The application of the scale to the register must, of course, be made before the exposure of the latter to the fire, and also after its cooling: and the object sought is, to ascertain precisely how much the index *c c′* is pushed out by the expansion of the metal when heated. This scale is made of two rules of brass accurately joined together by a right angle at their

edges, and fitting square upon two sides of the register. The greater rule is ff', and the smaller g. When the scale is thus fitted to the register, the projecting piece of brass h rests upon the ledge, under the platinum band d: so that thus, the scale is firmly united to the register; and we must now see how it acts.

Fig. 6.



At the upper extremity of this frame is fixed an apparatus, which corresponds to a pair of proportional compasses, the whole of which is movable at a screw i, which part projects so as to come exactly over the hole in the register. The connexion of the two arms is made by a screw at k. The arm D, which is $5\frac{1}{2}$ inches long, carries an arc of a circle, whose radius k H is 5 inches; this arc is graduated into degrees and thirds; subdivided by the nonius H into minutes; which may be read off by the magnifying-glass at l, the stem of which lies on the bar C between l and H, and is so arranged as to bend twice, in order that the glass may project horizontally over the nonius. The other end

of the arm C terminates in a point *m*, which is half an inch from *k*, or $\frac{1}{10}$th of the radius *k* H. In making a measurement this point *m* is fixed into a small hole in the index at *c*. When this is effected, the part *m k* acts as the smaller arm of a lever, and the radius *k* H will begin to move from zero, which point it is always kept to by a spring at *n*, until forced away by the action of the point *m* at *c*:—hence, the arc described by the point *m* is increased ten-fold on the circle at E. The little arc is of course due to the index at *c c′*, having been pushed out when the metal expanded; which arc is thus appreciated by taking its decuple. The chords of these arcs are easily found by computation; and that of the smaller gives the amount of the advance of the index, or of the metallic expansion. The degrees given on this scale are made to bear relation to those of the mercurial scale; so that, as the ratio is marked on the instrument, the degrees of the scale are convertible into those of Fahrenheit. The graduation was performed by Mr. Troughton's dividing engine, to which we allude in the paper on the Vernier (33).

187. One advantage in the construction of this pyrometer is, that the material whose expansion is to be measured is quite detached, during the heating process, from the instrument of measurement; so that the scale, vernier, &c., not being exposed to the fire, are not subject to an expansion, which would necessarily interfere with the correctness of the results.

188. Professor Daniell gives the rule, by which he is enabled to calculate the linear expansion of the metal-bar, by means of the arc described by the smaller division of the graduated arm. Into these details, however, we need not enter; but may merely state that Professor Daniell gives the following as the expansions, at different temperatures, at and under a degree. The first column shows the arc moved over by the radius; the second, the linear expansion of the bar of metal: and the third, the temperature:—thus, if the radius move 1°, the bar is elongated ·00872 of an inch, and the temperature is 450°.

			Inch.		Temperature.
1°	0′	=	·00872	=	450°
0	30	=	·00436	=	225
0	20	=	·00290	=	150
0	15	=	·00218	=	112
0	10	=	·00145	=	75
0	5	=	·00072	=	37
0	2	=	·00029	=	15
0	1	=	·00014	=	7·5

189. Several different forms of pyrometers have, within a few years, been constructed by Breguet of Paris; of which we may describe one of the most approved. A slip of gold is interposed between two slips of platinum and silver, and the combined layer is then drawn to a great degree of thinness, being only $\frac{1}{1200}$th of an inch; after which it is curved into the spiral form; at the bottom of which is an index which turns round a graduated circle. When this coil or spiral is heated, it elongates; and that elongation is rendered perceptible by the lower end, to which the index is attached, slowly moving round, to accommodate itself to its expanded state; and thus the degree of elongation may be measured with the aid of the graduated circle.

190. It will be seen that, in order to mark an exceedingly wide range of temperature, *three* modifications of the principle of expansion and contraction are adopted. The following table will afford examples of results, as obtained by the three varieties of instruments respectively.

As indicated by Spirit-Thermometer.

Fahrenheit.	
— 135°	Greatest artificial cold that has yet been observed.
— 121	Solid compound of alcohol and carbonic acid melts.
— 91	Greatest artificial cold as measured by Walker.
— 55	Greatest natural cold observed by Parry.—NOTE. Ross states it at 60°.
— 50	Cold observed at Hudson's Bay.
— 47	Sulphuric ether congeals.

As indicated by Mercurial-Thermometer.

Fahrenheit.	
— 39°	Melting point of solid mercury.
— 23	Observed on the surface of the snow at Glasgow, 1780.
— 7	A mixture of equal parts of alcohol and water freezes.
— 7	Brandy freezes.
+ 16	Oil of turpentine freezes.
20	Strong wines freeze.
25	Human blood freezes.
28	Vinegar } freeze.
30	Milk } freeze.
32	Ice melts.
36	Olive-oil freezes.
50	Medium temperature of the surface of the globe.
52	Mean temperature of England.
96	Ether boils.
98	Heat of human blood.
174	Alcohol boils.
212	Water boils.
442	Tin melts. Lead 594°.
662	Mercury boils.

As indicated by Daniell's Pyrometer.

Fahrenheit.	
+ 773°	Zinc melts.
980	Red heat.
1141	Heat of a common fire.
1869	Brass melts.
1873	Silver melts.
1996	Copper melts.
2016	Gold melts.
2786	Iron melts.
3280	Temperature of the maximum expansion of platinum.

191. Before we dismiss the subject of the thermometer, we will give a brief account of an instrument for measuring very minute changes in temperature, of which the instruments before described are altogether incapable. It is obvious, that there is a large number of temperatures within the range of only one degree on Fahrenheit's scale; and analogy would lead us to suppose that there are many states of matter, inorganic as well as organic, which, if they do not absolutely depend upon such small changes in temperature, at least owe many of their modifications thereto. Our knowledge of animate nature must obviously progress only in proportion to the progression of our instrumental aids. The chrysalis of a butterfly, and the insect itself, have been proved to possess temperatures essentially different; and yet this difference is but a fraction of a degree on Fahrenheit's scale. The means for determining so simple a fact as this must be invaluable to the natural historian; and such means we now proceed briefly to describe.

192. The Thermo-Multiplier, is an instrument contrived by Nobili and Melloni, for measuring small quantities of radiant heat. It consists of fifty small slips of antimony and bismuth placed parallel to each other, and forming a prismatic bundle, whose length is 30 millimetres, and its section 96 square cent. The two terminal faces are blackened. The slips of bismuth, which alternate with those of antimony, are soldered at the extremities, and separated, in the direction of their length, by some isolating substance. To the first and the last slip is attached a copper wire; both meeting at the end of two pins of the same metal passing through a piece of ivory fixed upon a ring. The space between the interior surface of this ring and the elements of the pile, is also filled up with an isolating substance. The free extremities of the two wires are made to communicate with a galvanometer; the movements of whose needle indicate when the temperature of the anterior surface of the pile is elevated above or depressed below that of the pos-

terior surface. The advantage of this contrivance is, that degrees of heat, so small as to be quite inappreciable by the most delicately constructed thermometers, are multiplied, as it were, by the multiplication of the number of pairs of metal plates; and thus produce a sensible effect on the galvanometer-needle.

By means of a joint, properly situated, the axis of the pile can be placed at various inclinations. To preserve the faces of the pile from lateral calorific rays, the pile is inclosed in tubes of metal, which are blackened within and polished without.

193. By the aid of the thermo-multiplier, many important results have been obtained in the examination of organic and inorganic nature; as also in the consideration of various problems connected with geology, physiology, and natural history. To enter into this subject now would far exceed our allotted space.

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194. Here we conclude our account of the Thermometer; an instrument of universal application in the arts, sciences, manufactures, and domestic arrangements. To enumerate its various uses, would be to remind the reader of every process, in which temperature is concerned; whereof we are enabled to estimate differences, which our senses are often inadequate to detect, and always incapable of measuring. The chemist would be bewildered in his operations, were he unable to measure temperatures:—the natural philosopher also regards the thermometer as indispensable to his inquiries:—the astronomer constructs his instruments with especial reference to its indications:—without it meteorology could scarcely exist as a science. It also assists to solve some of the most important problems of the geologist; and many of the deductions of the naturalist. These are only a few of its applications; the reader can easily supply more.

II.

THE BAROMETER.

You charmed, indulgent sylphs! their learned toil,
And crowned with fame your Torricell, and Boyle;
Taught with sweet smiles, responsive to their prayer,
The spring and pressure of the viewless air.
How up exhausted tubes bright currents flow
Of liquid silver from the lake below,
Weigh the long column of the incumbent skies,
And with the changeful moment fall and rise.
—How, as in brazen pumps the pistons move,
The membrane-valve sustains the weight above;
Stroke follows stroke, the gelid vapour falls,
And misty dew-drops dim the crystal walls;
Rare, and more rare, expands the fluid thin,
And silence dwells with vacancy within.—Darwin.

1. Nature does not, perhaps, furnish us with a more perfect instance of her economy than is to be found in the atmospheric air. This wonderful medium, which in ordinary circumstances is appreciable by none of our senses, is one of the mightiest agents in contributing to the beauty and utility of the globe on whose surface we dwell. Yet it requires the aid of science and reflection, to be convinced that the atmosphere is every where present, and that its powers are so energetic. We cannot judge of its presence by sight, except when a certain amount of vapour uniformly suspended in it, affords us the view of the blue sky, or of the distant blue-clad mountains. It does not appeal to our sense of smell, save when it wafts the sweet perfume from the rich lap of variegated earth. We feel it, only when it is in motion, "breathing refreshment on a fainting world." It refers in no way to our sense of taste; and we hear it only when another body, put into rapid motion, communicates motion to it also, and this again to our ear. And yet, deprived of air, no animal, no vegetable could exist;—no flame could burn, no sound could be heard, no light could be seen. Darkness would again move upon the face of the waters, as at the time before the Creator had excited into action the powers with which He had caused organic nature to be endowed.

2. The uses of the air in the arts of life are as numerous as those arts themselves. The air wafts our ships "from Indus

to the Pole;" raises water in our pumps; gives motion to various sorts of machinery; enables us to explore the treasures of the deep in the diving-bell, or to soar above the clouds in the balloon. The clouds themselves are supported by the air; the state of which regulates and determines what we popularly call "weather." The various forms of rain, dew, mist, and snow, by which natural scenes are so beautifully diversified and improved, depend upon the state of the air, and its relation with respect to heat. The great aërial ocean, therefore, is a source of importance, utility, and beauty, to all animated nature; and we are about to inquire into its properties; but chiefly with reference to an instrument by which the ebbs and floods of this ocean of air are marked. A person well acquainted with all these properties must have made no mean progress in scientific knowledge; but, generally speaking, the use of an instrument so well known, and so extensively employed as the Barometer, is too apt to engender such a degree of forgetfulness of the principles on which it is constructed, or on which it acts, that few persons are aware of the delightful field of inquiry into which they would be led in endeavouring to trace, and account for, the mode of operation, and the physical laws which determine the utility of this, as well as of many other mechanical contrivances which the ingenuity of man has invented for his own service. Yet such inquiries are, perhaps, among the best modes of attaining a knowledge of the principles of science; for, so linked are the sciences one with another,—so imperceptibly are the boundaries which separate them shaded off, that a thorough knowledge of the principle of construction, and of operation, of any one instrument, will lead us into more sciences than at first we should be apt to suppose.

3. There are, it is most certain, very many instruments which a moderately-intelligent member of society is in the habit of encountering and applying to his use, each of which, if studied in all its bearings, would afford a vast fund of valuable information, independently of the mere use to which the instrument itself is applied. Such an instrument is the Barometer; an apparatus whose action depends upon principles as beautiful, perhaps, as any in the whole range of philosophical inquiry. We propose, therefore, to consider,—*First*, the composition and physical properties of the atmosphere;—*secondly*, those instruments by which some of the properties of the atmosphere are ascertained and measured; and *thirdly*, the relation between the barometer and various meteorological agencies.

Section I. The Atmosphere.

4. The atmosphere belongs to that class of fluids which, for distinction's sake, is called *elastic*. This distinction is not strictly correct; for *all* fluids are elastic; that is, they can be compressed into a smaller space, and will regain their former bulk when the pressure is removed: but the range of compressibility in liquids is so very limited, that, for all practical purposes, it is sufficiently correct to designate them as *non-elastic*.

5. The atmosphere, then, is a compound elastic fluid, invisible, and inodorous, of which the constant component parts are oxygen and nitrogen. Carbonic acid gas, and aqueous vapour, together with other bodies, are always present; but, being due to irregular sources, they are not considered as component parts of the atmosphere.

According to the best experiments, the ordinary constituents of the atmosphere appear to be in the following proportions:—

	By measure.	By weight.
Nitrogen	77·5	75·55
Oxygen	21·	23·32
Aqueous vapour	1·42	1·03
Carbonic acid	0·08	0·10
	100·	100·

or speaking only of the two more important elements,—

Oxygen	21	23
Nitrogen	79	77
	100	100

6. In 1833, Mr. Hough Watson, of Bolton, made some experiments, which tended to prove that the quantity of carbonic acid in the atmosphere is subject to variation, due to locality. This is what may be reasonably expected, when we consider, that at each act of respiration, the human being sends forth carbonic acid into the surrounding air. From the mean of 19 experiments, made in the town of Bolton, Mr. Watson found that 10,000 volumes of atmospheric air contained 5·03 volumes of carbonic acid. To determine what effect was probably due to the manufacturing processes at Bolton, he renewed his experiments on Horrock's Moor, about three miles north-west of Bolton, and at a height of 584 feet above the level of the sea. The mean of twelve experiments at this station, gave 4·135 volumes of carbonic acid in 10,000 volumes of air—a

diminution of 0·895, as compared with the air at the town of Bolton.

7. Saussure has determined experimentally, that the upper strata of the atmosphere contain more carbonic acid than the lower; that the quantity undergoes a sensible diurnal variation, being greater during the day than during the night: and that the quantity generally, is greater in dry weather than in damp, when it is absorbed by the moisture of the soil.

8. In the course of Dr. Prout's experiments on the weight of atmospheric air, (to which we shall further allude presently,) (13,) he found, that when his observations were made during the prevalence of wind, (his station being at the western extremity of London,) the air blowing from the east contained a minute portion of oxygen less than that which blew from the west. The difference was exceedingly small; but still, it tended to show that the air which has passed over the busy streets of the metropolis, differs in its amount, not only of carbonic acid, but also of oxygen, from the air which has not reached those scenes. It is, however, only through the exquisite care with which Dr. Prout's experiments were conducted, that any variation in the relative quantity of oxygen in the atmosphere can be detected.

9. This invisible compound fluid,—the atmosphere,—possesses many of the properties of solid matter; but, at the same time, possesses many which are peculiar to gaseous bodies. In common with solid matter, it possesses the properties of impenetrability, inertia, mobility, and weight. These we may term the *mechanical* properties of air; and of these we will treat before we consider the properties which belong only to fluids.

10. *Impenetrability* implies an attribute by virtue of which no two bodies can at the same time occupy the same place, and is one of the chief properties which give rise to our notion of the word "matter." Now, that no two solids can, at the same time, occupy the same place, seems a truism, the bare mention of which is childish, because our senses have always told us the same thing. But when we come to consider an invisible fluid like air, the same evidence fails us:—we cannot *see* that it is true; and the proof of its truth becomes more desirable in proportion as it is more difficult. Now, that air, though invisible, possesses this property, is easily shown thus:—Plunge an inverted goblet into a vessel of water,—observing, however, that every part of its edge touch the surface of the water at the same moment; it will be found that,

whatever be the depth of the water in the vessel, the goblet will not get filled; for there will be a portion unoccupied by water, varying in extent with the depth to which the goblet is plunged. Now, this portion is occupied by the air which originally filled the goblet; and the circumstance of that air occupying less than its original bulk is no proof against its impenetrability, but only shows that it is *compressible*, or that its atoms are readily brought nearer together. But no pressure of the water will enable it quite to fill the goblet; thus showing that however the air may be compressed, it is never annihilated. If the goblet be introduced obliquely into the water, the air will have time to escape before it is imprisoned between the glass and the water. Again, if a diving-bell be plunged to any depth into the sea, it never becomes quite filled with water:—at 34 feet below the surface, it is exactly half filled, from causes to be afterwards explained.

11. *Inertia* and *mobility* are those properties, by virtue of which a body will not move until it is forced to do so by some active power, and, when in motion, will not stop without some equal preventive power. Now, that air possesses these properties, is at once evident from the phenomenon of *wind*, which is nothing more than moving air. When we stand still on a calm day, we feel no wind; but if we run, the face feels as if a wind were blowing upon it. Now this arises from the first of the two properties just mentioned. The air will not move, unless some force impress it. Our bodies then become the moving force, and the degree of power necessary to move the air, is measured by the degree of wind which we feel on our faces; it is, in fact, an index of the reluctance of the air to begin to move. But when air is once in motion, as in the case of ordinary wind, we find that as much force is necessary to stop it, as was required to put it in motion; and the degree of force with which the wind rushes against any stationary object, measures the power necessary to stop its motion. Thus, when a hurricane, such as frequently occurs in the West Indies, levels buildings to the ground, and tears up trees by the roots, we are convinced that the air is moving with a velocity which requires, for its complete suppression, a power greater than that by which a tree clings to the earth, or a building to its foundation.

12. To these properties we will now adduce *weight*. That air possesses weight is, to a novice in philosophy, one of its greatest wonders. It has, however, been accurately determined,—by weighing a vessel containing a given quantity of pure air,

i. e., air deprived of its carbonic acid and aqueous vapour, and then, after extracting the air, weighing the vessel again,—that 100 cubic inches of atmospheric air, when the thermometer indicates 60°, and the barometer 30 inches, weigh rather more than 31 grains, which is about $\frac{1}{815}$th part the weight of water.

13. The means by which Dr. Prout has determined the weight of atmospheric air may be instructively shown here, as a fine example of the rigour and delicacy with which such inquiries must be conducted, in order to obtain satisfactory results. The air about to be weighed was (as detailed by Dr. Prout, at the Oxford meeting of the British Association, in 1832,) passed through lime water, into a large bell glass receiver, where it remained six or eight hours, with the view of separating the carbonic acid present. One portion of it was then introduced into a smaller but similar apparatus, filled with the strongest sulphuric acid; while another portion was conveyed into a similar apparatus, filled with distilled water. With these fluids, the two portions of air were respectively permitted to remain in contact for at least twelve hours; with the view, in the one instance, of separating from the air the whole of the water present, and in the other instance, of saturating the air with that fluid. A known quantity of air in each state, as determined by a very simple gasometer, was then introduced into the weighing balloon or vessel, and the weight of each quantity was carefully determined, with all the necessary precautions. In weighing air at 32°, an apparatus on the same principle was employed; but so constructed that the whole gasometer might be surrounded with ice, for some hours before the air was weighed. The weights employed were of platinum, and adjusted to the national standard. The measures of capacity were determined from the weight of water at 62°, of which 252·489 grains was taken as the weight of a cubic inch.

14. With these contrivances, and from a mean of eighty-seven experiments, Dr. Prout found that 100 cubic inches of the dry atmospheric air, free from carbonic acid, at the temperature of 32°, and barometric pressure of 30 inches, weighed 32·7958 grains; the extremes of difference being 0·0507 grains. These experiments show (as might be expected) that the weight of a given bulk of air is greater at 32°, than at 60°.

15. Although the delicacy of such experiments prevents them from being carried on in a familiar manner, yet, that air *has* weight, is abundantly shown in other ways. We know, for instance, that the silk, car, &c., which form a balloon, possess *weight*; and yet it ascends in air:—this shows that the balloon,

with the carburetted hydrogen contained in it, is not so heavy as an equal bulk of atmospheric air. The same remark will apply to clouds, which we know to be composed of water, and, therefore, to possess weight; yet they are upheld at a considerable elevation, merely because the air beneath them is, bulk for bulk, heavier than the clouds.

16. Now, from these four properties, viz., *impenetrability*, *inertia*, *mobility*, and *weight*, we might trace a great range of atmospheric phenomena. But the influence which two other agents,—*heat*, and *aqueous vapour*,—exert on air, is so extensive, that it is impossible to arrive at just notions on the subject, without first considering those agencies. The articles "Thermometer," and "Hygrometer," contain extensive details on these subjects; but it will be desirable for us, in this place, to state so much as is immediately connected with our present article.

17. Whatever may be the nature of heat, whether material or not, we know that one of its most important effects is the expansion of any body into which it enters; and thus, by removing the component particles of such body farther from each other, it renders any given bulk of the body lighter than it was before the application of heat. In solids this expansion is very limited, and requires very nice investigation to measure it. In non-elastic fluids, such as water, mercury, alcohol, &c., the expansibility is much greater. But it is greatest in elastic fluids, such as air; for the attraction of cohesion being entirely non-existent among its particles, any foreign agent, tending to remove the particles farther asunder, is aided in that object instead of retarded. In illustration of this we may state, that if a given bulk of *steel*, at 32° of temperature, be heated to 212°, its bulk is increased by about $\frac{1}{350}$th part of the whole; and glass nearly in the same degree. In liquids, the ratio is so much increased, that with the same increment of temperature, mercury expands about $\frac{1}{63}$rd, water about $\frac{1}{25}$th, and alcohol about $\frac{1}{9}$th:—those being the most expansible, which boil at the lowest temperature. But the expansion of air, under the same circumstances, amounts to more than one-third of the whole bulk. This, however, is not the most important point of distinction between the relative expansibilities of bodies in different states. It is found that solids and liquids expand in a greater ratio, with a given increment of temperature, when they are near the boiling point, than at a lower temperature. Thus, steel (as we have said) expands $\frac{1}{350}$th, on being raised from 32° to 212° (or through 180°); but if we take half this range (or 90°), we shall find that the expansion is *less* than $\frac{1}{700}$th from 32° to 122°, and more than

$\frac{1}{700}$th from 122° to 212°. The same applies likewise to liquids; but in a less degree to mercury than to any other liquid :—hence its value for thermometers, on account of its nearly equable expansion.

18. But in gaseous fluids, the expansion is rigorously equal for every degree of temperature ; and it is a most important law, that all gases expand, not only equably with equal increments of temperature, but likewise equably with each other ; that is, $\frac{1}{480}$th of the whole bulk of the gas at 32 , for each degree of temperature, or 0·375 from 32° to 212°.

19. It is at once, therefore, obvious, that a most material change will take place in the equilibrium of an aërial mass, if one portion be, from any cause, more heated than that which surrounds it ; because, as the particles of which it is composed are subject to the same law of gravitation which regulates solid bodies, those which are most expanded rise to make way for those which, by a closer aggregation of particles, possess greater specific gravity. We shall hereafter see the immense importance of this adjustment of aërial particles.

20. The influence of heat in modifying the state of elastic fluids being thus shortly alluded to, we will now consider a distinction in elastic fluids which leads to many important results. Oxygen and nitrogen, whether considered separately, or in the combined state which forms our atmosphere, are *permanently elastic* fluids ; which means, that neither compression nor abstraction of heat has ever yet converted them into the liquid state. But with aqueous vapour it is different : as it is likewise with some of the gases. Aqueous vapour, or steam, is not *permanently* elastic ; as unless its temperature be maintained at a certain height, according to the density of the vapour, it resumes the liquid state in which it first existed. The same remark applies to mercurial and alcoholic vapours. Whether the gases, such as oxygen or nitrogen, might be liquefied by excessive abstraction of heat, accompanied by enormous pressure, is an unascertained point ;—it is sufficient, however, for our present purpose, to state, that no means hitherto tried have succeeded in that object.

21. The formation of steam from water goes on slowly, at almost every temperature ; but it is at 212° that boiling takes place, under the influence of the atmosphere :—if we remove that influence, by placing water in vacuo, it boils at about 72°. The elastic force of vapour, ascending in the atmosphere, is proportional to the temperature of the water from which it ascends ; and at a low temperature, the steam struggles

slowly and silently against the pressure of the superincumbent air.

22. Until within a very few years, it had been always supposed that the pressure which interferes with the rapidity of evaporation, is excited by the atmosphere *as a whole;* but the investigations of Dalton and Wollaston have rendered it probable, that to the aqueous vapour contained in the atmosphere is due all that pressure which retards evaporation. It is believed that the component parts of the atmosphere are not chemically combined, but merely mechanically mixed; that there are, in fact, four distinct and separate atmospheres,—oxygen, nitrogen, carbonic acid gas, and steam: that these atmospheres exist independently of each other, and exert pressure, independently, on the earth's surface (those pressures being believed to be in the ratio of the volumes of the different gases); and that they reach to different heights therefrom; the nitrogen atmosphere being 54 miles, steam 50 miles, oxygen 38 miles, and carbonic acid 10 miles. But the point to which we more particularly allude, is the recently-formed opinion, that the preventive pressure, by virtue of which evaporation and ebullition are retarded, is excited solely by the *steam atmosphere:*—that one sort of gaseous fluid offers no obstruction to the passage of another sort through it:—that the repulsion existing between the particles of a gas is exerted only against its own kind, and that it is that repulsive energy in the steam atmosphere which retards the formation and issue of steam from the surface of the liquids:—that if the air were *perfectly dry*, that is, free from the steam atmosphere, evaporation would go on to as great extent, from a liquid surface, as if no air existed above it:—and that there is a sort of contest always going on between the steam already formed and existing in the atmosphere, and that which is about to leave the surface of bodies of water,—the repulsive pressure of the one being opposed to the elastic tension of the other. Dr. Dalton has formed these views of the constitution of the atmosphere from these three experimentally-proved facts: 1. That two gases, mingled in any proportion, in a close vessel, are equally diffused through one another: 2. That if different gases be placed together in a vessel with water, and shaken, no pressure of one gas upon the surface of the water can confine another gas in the water,—each acting as a simple and independent atmosphere: 3. That the quantity and force of vapour of any kind will be the same, whether there be any air present or not, —it being entirely regulated by temperature. From these three facts, but more particularly from the two latter, Dr. Dalton con-

siders it to be established completely, as a physical principle, that, whenever two or more such gases or vapours as we have been describing are put together, either in a limited or unlimited space, they will finally be arranged, each as if it occupied the whole space, and as if the other were not present; the nature of the fluids and gravitation being the only efficacious agents. From this he further infers, that the total weight of the gases existing in the atmosphere which they compose, is proportional to the *volumes* existing at the surface of the earth. If the combined pressure of the two atmospheric gases, (the nature of which pressure we shall presently describe,) (28,) nitrogen and oxygen, be taken at 30 inches, he conceives that the nitrogen exerts 79, and the oxygen 21 hundredths of that pressure; which, as we have before said, (5,) is the ratio between the volumes of the two gases;—thus assigning 23·7 inches to the nitrogen, and 6·3 inches to the oxygen. The above is Professor Forbes's exposition of Dr. Dalton's theory.

23. As an increase in the temperature of water increases the tension of the steam generated therein, the rapidity of evaporation necessarily varies with every change of temperature. The manner in which a balance is maintained between the downward pressure of the aqueous vapour contained in the atmosphere, and the elastic tension of that which is forming in water, under the influence of heat, will be better understood by reference to tables of the elastic force of steam, such as we give in the article "Hygrometer." (12.)

24. Such a table will give an idea of the manner in which the giant power of the steam-engine is called into existence. Water, heated in a vessel of limited dimensions, generates a steam atmosphere within. This atmosphere, having no room for expansion, gradually increases in density and elastic tension, until at 212° it presses on the inner surface of its containing vessel with a force equal to the atmospheric pressure on the outside: but above this temperature its elastic power becomes enormously increased; so that at 302° it presses with a force of more than 60 pounds on each square inch of surface, and at 343° with a force of 120 pounds.

25. When we consider that the ocean covers about three-fourths of the whole surface of the globe, and that steam rises from water at every temperature, (but in different quantities according to the temperature,) the vast importance of that element of the atmosphere will at once present itself to our view.

26. We shall now proceed to detail the atmospheric phenomena which are brought about by the mechanical properties

belonging to the unvarying elements of the atmosphere,—oxygen and nitrogen,—and by the ever-changing proportions in which heat and aqueous vapour are mixed with it.

27. Air possessing weight, it necessarily follows that that portion of it which is nearest the surface of the earth has to bear the pressure of all which is above it, and becomes, therefore, more condensed. Now, when we say (12) that 100 cubic inches of air weigh about 31 grains, at mean temperature, we allude to air taken from that stratum which is nearest the earth: but it has been found, as just stated, that its specific gravity decreases as it is further removed from the earth. This has been proved at all the heights which man has been able to reach; and calculations, founded on the rate of expansion at accessible heights, have determined the limit of the atmosphere to be about 50 miles. Many have supposed this rarefaction to go on into infinite space; but the most distinguished philosophers agree in opinion, that beyond a certain distance, centrifugal force, which increases the further removed it is from the centre of the earth, and the diminution of gravitating attraction, are compensated by the extreme tenuity of the air, and a lessening of the repulsive tendency of its particles, whereby they are prevented from receding farther from the earth. But although we cannot tell the weight of a given bulk of air at the highest stratum, yet we find that a column of air one inch square, reaching from the earth to the summit of the atmosphere, weighs about 14½ pounds; and, as we likewise know that a cubic inch at the earth's surface weighs somewhat less than one-third of a grain, we can calculate that, if the atmosphere were of *equal density* throughout, it would be between four and five miles high.

28. That a column of air one inch square, and reaching to the top of the atmosphere, weighs 14½ pounds, is a fact that common *weighing* will not indicate; but we find it from other evidence. The reason why weighing will not decide it, is to be found in a remarkable property which distinguishes fluids from solids; which is this:—If we take a solid body, (a mass of iron, for instance,) it presses only in one direction, viz., towards the centre of the earth, and exerts no lateral or upward pressure. But in fluids,—whether liquid or aëriform,—any impulse communicated to them spreads equally in every direction:—this results from the perfect freedom with which the particles move among each other, and is shown in numerous familiar examples. An orifice being made in the side of an open vessel containing water, the water rushes out with a force exactly equal to the

pressure which the body of water above the level of the orifice exerts on the water at that level. In the same way, if the vessel be quite full, and closed at the top, through which a tube shall pass to the water within,—the tube being likewise filled with water,—the upper stratum of water in the vessel presses, owing to the force of the column in the tube, upwards against the cover, with the same force with which it presses on the water beneath. So likewise, in aëriform fluids;—if a bladder be filled with compressed air, and a hole be made in it, the air will escape with just as much velocity, if this hole be made at the top, or the side, as if it were at the bottom.

29. It follows, therefore, that the pressure of $14\frac{1}{2}$ pounds on the square inch, which the atmosphere exerts at the earth's surface, is exerted equally in every direction; upwards, downwards, and laterally. It has been calculated, that the atmospheric pressure upon the body of a man of ordinary stature, amounts to no less than 15 tons, or 33,600 pounds avoirdupois.

30. Should the reader think this result incredible, and wonder how so enormous a weight can be borne without either crushing the man, subjecting him to a painful inconvenience, or impeding his motions, he is reminded that science requires that our reason should be exercised before our judgment is pronounced; and that we should not be eager to reject any result as absurd, simply because it appears astonishing. Besides this, the true philosopher is not in the habit of yielding to the sentiment of mere wonder. With him, an extraordinary result is sure to excite that industrious inquiry, which is the successful antagonist of gaping admiration. Whereas the mind of the ignorant man, which depends upon mere perception, and knows not

> Where Judgment sits, clear-sighted, and surveys
> The chain of Reason with unerring gaze,

views an extraordinary process of nature or of art with wonder, and is satisfied that wonder should remain; nay, he is often displeased if the truth be displayed to him in so luminous a manner as to dispel the cloudy garment of mystery which envelopes the cause of his admiration. But, to return.

31. A few examples will suffice to explain how it happens, that we are exposed to so enormous a force as the atmospheric pressure, without being sensible of it. There are certain kinds of fish, which inhabit the sea at very great depths. They are sometimes caught at depths varying from 2000 to 3000 feet below the level of the sea. These fishes, therefore, sustain a pressure of a column of water, whose height is 2000

or 3000 feet; that is to say, a pressure from 60 to 90 times greater than that of the atmospheric column upon our bodies. Yet, these fishes are not crushed by so enormous a weight:—not only do they live, but they swim about with perfect ease under circumstances apparently still more surprising than those which affect us. But the wonder ceases altogether when we consider that these fishes hold within their bodies certain fluids, which correspond to the pressure of the water without;—so that the membranes of these animals are in no wise injured, because the pressure, though intense, is equable on all sides. The fish moves with facility, because its body is equally pressed above, below, and around, the pressure counterbalancing itself;—and it is as easy for this fish to move about at a great depth, as for others nearer the surface of the water. In like manner we, who support the atmospheric pressure, have our bodies, and even our bones, filled either with incompressible liquids, capable of sustaining pressure; or with air as elastic as the external air. In short, every part of the human system being vascular, and containing air, the pressure from without is counteracted by that from within. Here, then, we arrive at the reason why we are not incommoded by the atmosphere. We find that we experience no difficulty in moving about, because the pressure of the air is counterbalanced at all parts of our body,—as the pressure of the water is counterbalanced at all parts of the body of the fish. We cannot be crushed by the external air, because (as Professor Robison observes,) the human body immersed in the atmosphere, may be compared to a sponge, which is not crushed by the weight of water upon it, however deep it may be plunged into the sea, simply because there is water within the cavities of the sponge as well as without. We cannot then be crushed by the external air, unless it were possible to annihilate the air within us, which preserves the equilibrium; and, on the contrary, if the external pressure were suddenly removed, and we were placed *in vacuo*, the internal air, no longer having any thing to resist it, would expand; and we should inevitably burst and perish. This is, in fact, what would occur if a man were suddenly removed 100 miles upwards from the surface of the earth. Indeed, a comparatively small height produces painful effects on man. On the 7th of November, 1783, Zambeccari and his companions ascended so high in a balloon, that their limbs swelled; and they feared that, had they continued to ascend, some of the smaller vessels of the body must have burst. The gas, too, contained within balloons, expands in proportion as the atmospheric pressure is diminished by ascent; so that a

balloon would inevitably burst, but for a contrivance of the aëronaut, to allow portions of the gas, adequate to the increased expansion, to escape. Fishes, such as we before alluded to, when drawn up from great depths, or even from a depth of nine or ten feet, expand to such a degree as to produce sudden death. Most of them have within their body a bladder filled with air,—not atmospheric air,—but a particular kind of gas, produced and secreted by the animal. So long as they remain at the depth in which they ordinarily live, the air contained within this bladder has the degree of compression and of elasticity necessary to support the weight of the water which presses upon them; but, if they be suddenly drawn from the water, having no conduits sufficiently large to throw off the superfluous air, and some not having conduits at all,—it follows, that their air-bladders must expand. Now, the contained air, filling their bodies, and thus often occupying a volume eighty or a hundred times greater than before, turns their stomach out through their gills; and thus they perish. In this state they float upon the water, and can no longer sink.

32. These examples show us how ridiculous many of the works of Fancy appear, which take no heed of the guidance of sound philosophy. Some of the tales and poems, put into the hands of young persons, place their heroes hundreds of leagues away from the earth, floating in space; sometimes these ideal personages are made to inhabit palaces below the sea; and this easy lore teaches the young mind that the very centre of the earth, or even the moon, is not of difficult attainment.

33. We are now in a condition to inform the reader why we cannot weigh the whole pressure of the atmosphere by ordinary means; the scale of a balance, for instance, being pressed *upwards* by the air beneath it in exactly the same degree as it is pressed *down* by the air above it. But whenever we can free one side of any object from atmospheric pressure, we can then ascertain the amount of force pressing on the other side; thus, in a well-known experiment, two hollow hemispheres are simply placed edge to edge, but without any mode of fixing or securing. The air is then extracted from the central hollow, and it is found that the two halves cannot be separated by a less force than fourteen times as many pounds as there are square inches on each section of the sphere. The power of a fly to fix itself on the ceiling or wall of a room depends upon this upward and lateral pressure of the air. There is a muscular power by which the fly is enabled to form the bottom of the foot into a hollow shape, between which and the ceiling a

vacuum exists: he is then upheld by the pressure of the air against the opposite side of the foot. Again, in the operation of cupping, the air is removed from a small external part of the body, in consequence of which the internal air thrusts out the skin, and with it the blood-vessels near the part, and makes a protuberance. Similar instances are numerous, but these will suffice.

34. Having thus shown the nature of the pressure which the atmosphere exerts on all bodies at the earth's surface, we will proceed to the consideration of the manner in which this pressure gave rise to the invention of the Barometer.

35. For nearly 2000 years, the common Pump has been in use for the purposes to which it is at present applied, viz., the raising of water from depths which could not otherwise be conveniently reached; or, at least, whether it has been *used* so long or not, its adaptation to that purpose was known; but for 1700 years afterwards, the principle on which its action depends was unknown. In the middle ages, the convenience of its application was sufficient to satisfy the minds of those who used it, without suggesting any inquiry into the causes of the phenomenon; indeed, the state of mind, among nearly all classes in those ages, was based upon such erroneous grounds, that an inquiry into the laws by which the Creator so beautifully governs the universe, was looked upon as an unhallowed presumption: the mind was permitted to rust, for fear that its polish should reflect too much light. But, happily for mankind, the age of Galileo arrived, and with it a more just and ennobling tone of thinking, the fruits of which subsequent ages have amply gleaned.

36. The ancient philosophers were wont to explain natural phenomena by a series of dogmas of universal application, which, through the writings of Aristotle and others, were for many ages taught and persisted in, with the melancholy perseverance in error which but too often characterizes the human mind. Thus, the removal of air from a tube, by means of the mouth, or by a piston, and the consequent ascent of water in the tube, was explained by referring to Nature a great abhorrence of a vacant space. A tube being placed, one end in water, and the other end in the mouth;—if, they say, the air be "sucked out," water will rise and fill the tube, because "Nature abhors a vacuum." Nobody thought of asking how Nature (which is nothing more than the pre-ordained course of physical phenomena, taken as a whole,) became thus personified, and transformed into a being susceptible of passions.

But at this epoch, doubt was not invented; and it was only the occurrence of a real and positive inconvenience to man, that led the way to a knowledge of the simple cause, why water rises in an empty tube.

37. Certain Florentine engineers, having caused a well to be sunk, and a pump to be erected, found that the water would not ascend to the surface. All were astonished at this fact, and the cause was discussed with great eagerness. Upon inquiry into the circumstances, it appeared that the distance from the piston of the pump to the water in the well, was more than 18 palms, or 34 feet, and that this appeared to be the source of failure.

Galileo was consulted; and it is now a matter of doubt, whether his solution of the difficulty was given satirically or seriously. His reply was, "that Nature's abhorrence of a vacuum extended only to the height of 33 feet." This peculiar predilection of Nature for a certain number of feet, was a capital idea for the mass of wonderers, as it furnished an easy solution of the difficulty; but Galileo, and a few of his distinguished pupils, Torricelli, Viviani, and Ricci, were not so satisfied. If, indeed, they were aware of the true principle, they now saw how it might be applied; but if, as is most probable, they were ignorant of it, then the manifest absurdity into which this dilemma had drawn them, would stimulate their vigorous minds to search for and discover the hidden principle: and, indeed, we have every reason to suppose that, from the circumstance above noticed, they turned their attention to the subject, and elicited results which finally gave birth to the barometer.

38. The great question to solve was, "Why does water rise in a pump?" A principle of *suction* had been advocated. The piston was said to suck the water out of the well; but Torricelli conceived that it might be the pressure of the external atmosphere which forced the water up into a barrel from which the piston had previously extracted the air. We may suppose him to reason thus: that the vertical pressure of a column of water 33 feet high, equals that of the entire height of the atmosphere; and (as a necessary consequence of this hypothesis, if true,) it will equal the pressure of a column of any other fluid, of a height in the inverse ratio of its specific gravity as compared with water; of a greater height if the fluid be lighter, and of a less height if it be heavier, than water; which ratio would assign to mercury a height of about $2\frac{1}{2}$ feet.

39. To test this opinion, he took a glass tube, 3 feet long,

and closed at one end; filled it quite full of mercury, and then inverted it into a basin of mercury, preventing the admission of air into the tube by covering the open end with the finger. The finger was then removed, and a communication opened between the mercury in the tube and that in the basin; when the mercury in the tube sank at once, and stood at the height of nearly 30 inches.

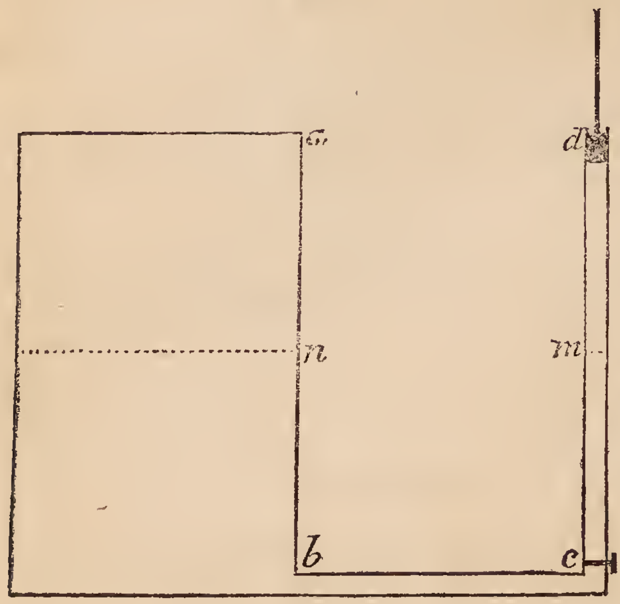
40. Here was a confirmation of his views. The mercury in the basin was pressed in one part by the column of mercury 3 feet high, and in every other part by the superincumbent atmosphere. The former proved to be, for a given horizontal surface, the greater pressure of the two; and the mercury fell, and formed such a column as exactly balanced the atmospheric pressure. Now it can easily be determined that a column of water, an inch square and 33 feet high, and a column of mercury an inch square and 29½ inches high, each weighs between 14 and 15 pounds; and from this conjoined testimony Torricelli concluded, that a column of the atmosphere, an inch square, and reaching from the earth to the summit of the atmosphere, weighs between 14 and 15 pounds.

The manner in which this principle acts with reference to the common pump, we will now proceed to detail, as it is intimately connected with our object.

41. The cylinder, or rather, the suction-pipe, of a pump, is, in every instance, immersed in water, which is in connexion by means of springs or other channels, with a reservoir of water open to the action of the atmosphere, which exerts a constant pressure upon its surface. This pressure,—by the peculiar nature of fluid bodies, before alluded to,—is equably diffused over the whole extent of the fluid, however numerous may be its ramifying branches. Consequently, if one angle, stream, or branch, be for a moment relieved from confinement or pressure, in an opposite or transverse direction, the external force impressed by the atmosphere drives it onwards. This impulse, if communicated either in a downward or a lateral direction, is almost unlimited, for gravitation aids it; but if it be exerted *upwards*, gravitation opposes it, and the limit to its upward motion we will now inquire into.

42. Let *a*, fig. 1, represent a reservoir, or cistern, from the lower part of which a horizontal tube, *b c*, springs, which afterwards takes a vertical direction, *c d*. Suppose a valve or cock placed at *c*, which, by opening or shutting, admits or prevents the passage of water from the larger vessel to the vertical tube, *c d;* and let the ends *a* and *d* be open to the atmosphere,

Fig. 1.



the valve at c closed, and the reservoir and horizontal pipe full of water. In this position, the valve is pressed on its upper surface, simply by the atmosphere which is resting on it; but on the under surface, the pressure is compounded of the weight of a column of water of the whole height a b, and of the atmosphere pressing on that column. The former source (the liquid pressure) is derived from the obvious circumstance that, in a body of water, as well as every other fluid,—liquid or gaseous,—each fluid stratum bears a greater weight and pressure than the stratum next above it; and, therefore, the water in the horizontal tube has to bear a great pressure at its left extremity, from this cause alone. This pressure, when aided by the atmospheric pressure on the water in the cistern, gives a combined force, acting on the lower surface of the valve, much greater than that sustained by the upper surface; the consequence of which necessarily is, that, on opening the valve, the water rushes up the small pipe, by virtue of the greater pressure in that direction, and the condition of equilibrium is attained when the water is at the same level in both tubes. The reason of this may be thus explained: no communication can take place between the reservoir and the vertical tube, excepting through the horizontal pipe; and any progressive motion of the water in this pipe is determined by the balance of pressure at its two extremities, b and c. Now those two pressures are equal when the heights of the water in the reservoir and vertical tube are equal; and when that equality of height is attained, equilibrium throughout the whole liquid results. It might be supposed at first sight, that the larger *bulk* of water would exert the greater pressure, and that, therefore, when the heights were equal, the part b would bear a greater burden than c; but this is prevented by the remarkable property of the equalization of pressure in fluids, by which every particle bears a share in the burden of any additional pressure; and as the *source* of this pressure is from above downwards (being the result of gravitation), the amount of pressure on any given space at or near

the bottom, is measured solely by the *vertical* height of the fluid above it, without regard to its *bulk;* in other words, the pressure on the entire bottom of the vessel is estimated by the vertical and lateral dimensions, conjointly, of the water above it, but the pressure at any *given point*, is referred to the height only.

43. Now this is the universal principle by which fluids always attain the same level, if in communication with each other. The even surface of a lake,—the rise of the water in a ship when a hole is broken in the hull,—the supply of a city with water from an elevated reservoir,—all relate to the same cause, viz., the balance of *vertical* fluid pressure (aqueous, or aërial, or both) at any two points.

These, then, being the steps by which liquid bodies attain equilibrium, and these the conditions which determine its continuance, we will now inquire into the effects which a vacuum would produce on this equilibrium.

44. Suppose (referring again to fig. 1) there be sufficient water to fill only a part of the large vessel, the valve at *c* being open, and the water at equal heights in the reservoir and the vertical tube. Let an air-tight piston, *d*, with a valve opening upwards, be now fitted to the tube, and capable of working vertically in it; and let it be sunk to the surface of the water therein at *m*. Upon raising the piston by means of an attached rod, the air resting upon it is carried up with it, none of which air can again penetrate below the piston, because the valve opens upwards. When, therefore, the piston is raised to the top, we get a vacant space between it and the surface of the water at *m*; so that the atmospheric pressure is entirely removed from the latter. This at once disturbs the equilibrium of every particle of water throughout the apparatus. The water at *b* is pressed by the aqueous column, *n b*, and by the air above it; while *c* is pressed only by the aqueous column, *m c*. In consequence of this unequal pressure, a movement goes on from *b* to *c*, until the water has ascended to such a height in *c d*, that the increased aqueous pressure at *c* shall equal the combined aqueous and atmospheric pressure at *b;* and when that equipoise is attained, no further rise will take place in *c d*, whether there be still any vacuum above the water or not.

45. Now, as the principles on which nature acts are constant on a large and small scale, this figure and this train of reasoning will equally avail for a table-apparatus, and for a large lake with streams flowing from its bed; viewing it in which latter light, we at once come to the principle of the

common pump, and to the extremely important consequences which Torricelli deduced therefrom.

46. The well into which the barrel of a pump dips may, in all cases, be represented by the tube *c d;* as it is invariably in connexion, by horizontal or inclined channels, such as *b c*, with some reservoir of water, the fluid level of which determines the height to which the water will rise in the well. If that level be on some mountainous tract above the general level of the ground near the well, the water will rush out of the latter, and form a fountain. If the reservoir be a neighbouring lake on the same level, the well will be filled to the top, but without running over. But in most instances the source is an aggregation of small streams, which collect and form a reservoir below the general surface of the earth; and at whatever depth that reservoir may be, the water in any fissure connected with it will be at an equal depth from the surface of the ground; and as wells are nothing more than such fissures, either natural or artificial, the depth to which we must apply our apparatus for raising the water in the well will be equally determined. This being premised, we can now conceive the tube *c d* to represent a pump-barrel, in which the water rises to *m*, by being in connexion with a reservoir, *a b*, filled to *n*, through the medium of an underground channel, *b c*. The piston need not be thrust down to *m;* for if it work through a small range of distance near the top, *d*, it will extract the air by small quantities at a time. At each stroke the quantity of air in the barrel, *d m*, becomes less; and, as its elasticity makes every part of the remaining air share the effects of the resulting expansion, the density and pressure become less than that of the external atmosphere,—the underground channel becomes pressed unequally at its two extremities, —a movement takes place towards *c*, and the water gradually rises in the barrel: this it may to an extent of *thirty-three feet* above *m*, after which no working of the piston will give a greater elevation.

47. This is the rationale of all *suction*-pumps, as they are erroneously called. The water will ascend through 33 feet of vacuum, merely because the pressure of the external air will exactly balance such a column of water. If the density of the atmosphere were greater than it is, a greater column of water could be supported by it; it follows, therefore, that if a common pump were capable of being used at the bottom of the tin mines in Cornwall, (some of which are nearly 2000 feet deep,) it would be found that a greater column of water could be supported by the air than at the top of the shaft, on account of the

increased density of the air below. Again, if we were enabled to work a pump at the top of a mountain 4000 feet high, we should find that the water would rise but 27 feet in the barrel, on account of the decreased density of the air.

48. It might be thought unnecessary thus to go into the principles of the common pump, to prove the principle of the action of the barometer. But the connexion between the respective phenomena is so great,—the rationale of the one is so elucidative of that of the other,—and Torricelli's investigation was so entirely suggested by the consideration of the action of a pump,—that we have deemed the details into which we have entered as a proper part of our subject. We are now, therefore, prepared to enter upon the construction of the Barometer.

Section II.—Barometrical Instruments.

49. The tube of mercury prepared by Torricelli, being an indicator of the atmospheric weight, or pressure on the open mercury in the basin, was thence called a *Barometer* (from two Greek words, *μετρον*, *measure*, and *βαρος*, *weight*). The term is, perhaps, not judiciously chosen; for a "*measurer of weight*" might equally apply to the common balance, steel-yard, &c.; —whereas the barometer can only measure fluid pressure.

50. The same process always produced nearly similar results; and the fact became established on a solid and enduring basis, that the atmospheric pressure is equal to that of *about* 30 inches of mercury. But it was soon found that the mercury was not always of one height in the same tube,—sometimes ascending to nearly 31 inches,—and at other times descending to not much above 28. The inquiry into the causes of this difference, may almost be said to have laid the foundation of the study of Meteorology*, which two hundred years of observation and experiment have scarcely sufficed to raise to the rank of a science; for the laws which regulate the fluctuations of the atmosphere are not yet reduced to an available code. We are, up to the present day, merely pioneers, preparing the way for practical results in the future: an immense store of facts has been collected; but the time for digesting them into one harmo

* This word is derived from the Greek *μετεωρα*, *meteors*, and *λογος*, a *discourse*. In common acceptation, meteors are always considered to be *luminous* objects; but the meaning of the original is *high* or *elevated*, and was applied to phenomena which occurred in the upper parts of the atmosphere.

nious whole, and accounting for the whole by one connected chain of induction, is not yet arrived. We shall therefore briefly consider the principal facts connected with the rise and fall of the mercury in the barometer, without attempting to reduce them to a systematic arrangement. This latter will find a more appropriate place in the next section;—the present being devoted to a description of the instrument itself.

51. The essential part of the common barometer is a glass tube, 33 or 34 inches long, containing mercury:—all the other appendages being merely conveniences for indicating, more accurately, the height of the mercury in the tube. In constructing a barometer many precautions are necessary, which we now proceed to detail.

52. The mercury must be perfectly pure. The metal, as it is sold in the shops, is frequently adulterated with tin, lead, zinc and bismuth; all which metals the mercury dissolves and holds in solution. Now not only does the presence of these metals in mercury detract from the mobility of this fluid, and thereby render it less sensible to the varying changes of the atmosphere;—but, as the height of the mercurial column depends upon the density of the mercury (pure mercury being the standard), the height, indicated by a column of the adulterated metal, will always be greater than that of the pure metal. The reason for this will be well understood by considering the specific gravities of the four metals named above: viz.—Mercury 13·568, Lead 11·352, Bismuth 9·822, Tin 7·291, Zinc 6·870. In our article on the "Thermometer" (131) we have briefly stated how mercury may be purified.

53. Supposing, then, that we have obtained pure mercury; and that we are provided with a clean glass tube, closed at one end, and of uniform bore throughout; the tube must be filled with mercury, so as to exclude entirely the presence of air and moisture. The reader may possibly imagine this to be an easy affair; and suggest that all that is required, is to pour the mercury into the tube, and, placing the finger on the open end, to reverse it when full into a cup of mercury: but such a plan would afford a very imperfect barometer. The fact is, that the filling of the tube in the construction of a good barometer, is no easy matter. We proceed, therefore, to show *first*, why the plan just proposed will not succeed: and *secondly*, the means actually adopted, in order to supply the scientific as well as the ordinary observer with an instrument of such great utility.

54. Mercury, like all other fluids, absorbs air, which becomes mixed with it, and intimately, though mechanically,

combined with its very substance. The air is absorbed by the attraction of the mercury for it; and, when once absorbed, it is prevented from escaping, in consequence of the atmosphere pressing upon the surface of the mercury, and preventing the manifestation of the natural elasticity of the combined air. Now, if such mercury be suspended in a tube, and a vacuum be left between the top of the tube and the upper surface of the mercury, the combined air, being relieved from pressure, will escape in bubbles, which will traverse the mercury, and burst at its surface. This air then expanding in the interior of the tube, will oppose the pressure of the external air, partly counter-balancing it in virtue of its own elasticity, and consequently, forcing the mercurial column to descend lower than it would if the vacuum above the mercury were complete;—so that the observed height of the column no longer shows the true pressure of the atmosphere, but only the excess of the pressure above that within the tube. It will be seen then, that, in order to get at the true pressure, we must begin by extracting all the air mixed with the mercury:—which is effected by boiling it, before filling the tube. Heat, augmenting the natural elasticity of the combined air, forces it to separate; and when once the bonds of affinity which connected it with the mercury are loosened, it escapes in bubbles through the liquid. It is boiled for about half an hour, and then the vessel is closed carefully, and the metal allowed to cool; and thus it is preserved for use.

55. But this is not all. Experiment proves that the molecules of watery vapour and of air adhere very strongly to the surface of glass; and, as water in a state of vapour always exists in the air, it happens that a thin layer of water and of air adheres strongly to the interior surface of the glass tube. In order to prevent the introduction of dust, air, and moisture, it has been recommended to seal the tubes at both ends before they are sent from the glass-house. When about to be used, a file will easily open one end of the tube. But even with this precaution, the simple act of pouring mercury into the tube is sufficient to cause air, and even vapour, to be introduced; so that this plan will still be inadequate to the removal of this adhesive layer of air and vapour. If such a tube, then, be employed for a barometer without preparation, and mercury be poured into it, so as to fill it,—then, when the tube is inverted into a cup of mercury, and the mercurial column has descended to the usual height, the adhesive layer of air and water will be no longer subject to atmospheric pressure, and the same thing will happen to it as to the particles of air confined within the

mercury before boiling: that is to say, a portion of this layer will escape from the attraction of the glass,—will be formed into elastic vapour in the interior of the tube, will ascend into the Torricellian vacuum, and by its elasticity will tend to balance the pressure of the external air; so that by the action of this second cause also the barometric column will be too low. The only resource, then, that we have, in order to remove this layer of moist air, is to heat the tube so strongly as to disengage it; and this operation should even be repeated after the introduction of the mercury into the tube; as moist air may re-enter even in the very act of filling the tube, and again adhere to its sides. The best and surest method, therefore, to avoid every source of error, is to pour mercury in small portions into the tube, and to heat it to the boiling point of mercury after the introduction of each portion.

56. The student may think this operation to be difficult indeed:—he may say that glass, and especially the thick glass of which barometer-tubes are formed, is so fragile a substance that it cracks by the sudden application of heat, and that in this operation the tubes would be constantly breaking. Nevertheless the process is very easy, when precautions are taken. When a body which is suddenly heated, breaks, its rupture is not occasioned by the action of heat alone, for this action tends to fuse the body,—not to break it. The rupture is due to the unequal action of the heat; which, exerting itself differently upon different parts of the glass, expands them unequally. If the expansion be slow and gradual, the body, yielding by degrees, experiences the effect of heat, without breaking; but, if the neighbouring parts be suddenly expanded in very different proportions, they can no longer obey, as a whole, the action of such unequal forces. If the effort which they make be sufficiently energetic to overcome the attraction of cohesion which unites the particles of the body, they separate, and the body breaks; so that, to avoid rupture, it is only necessary to heat the body gradually. It will be seen, then, that mercury may easily be boiled in a glass vessel; and the process becomes easy, in proportion as the vessel is thin; because, then, the heat pervades the whole mass with greater readiness and facility.

57. We will now explain the process of boiling the mercury in the barometer-tube, while filling the same. A small plumbago furnace is provided, containing ignited charcoal, and so disposed as to produce no flame, for this would certainly break the tube by coming in contact with it. The empty tube is presented to the fire, but at a considerable distance from it at

first; then nearer; then nearer still, until at length it is strongly heated; at the same time, it is kept turning round, in order that all its parts may be made equally hot, and it is moved over the fire in the direction of its length. The object of this operation is to remove moisture from the tube; for if we waited until after the mercury had been poured in, such moisture, being converted into steam or vapour, would not only expel the mercury from the tube, but might even produce an explosion sufficiently violent to shatter the tube to pieces. The tube being thus dried while it is yet warm, some of the well-boiled mercury obtained in the former process is to be gently heated, and poured into the tube in quantity sufficient to occupy a length of two or three inches. The tube is again held over the fire, with the same precautions as before, and is gradually heated until the mercury boils. After boiling for a minute or two, the open end of the tube is to be closed with a cork, to prevent the introduction of moisture, &c.; and so it is allowed to cool a little. This operation should be conducted in a room with open windows; or, at least, in a very large room; so that the vapours exhaled by the mercury may not incommode the operator. When the tube is cooled, a second portion of heated mercury, equal to the first, is poured in. It is again boiled; and this process is continued until the tube is nearly full, observing that the fire must be brought immediately under the mercury last poured in. A small portion of the tube will now remain without mercury, which portion must be filled up as before, but not boiled again; for, if it were, we should be unable to keep the tube entirely full. The finger must now be placed upon the opening with the most rigid precaution, to prevent the introduction of air. The tube may now be reversed, and plunged into a cup of mercury, as usual; then the column sinks, and expels the last portion of mercury which had not been boiled, and as there is neither air nor elastic vapour above the mercurial column, its length exactly measures the pressure of the atmosphere.

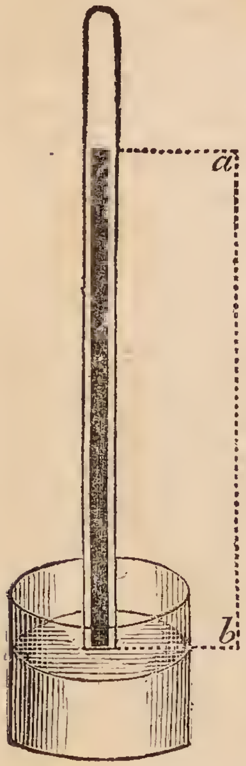
58. We may generally know when the Torricellian vacuum is perfect, by holding a barometer in the hands, and suddenly inclining it a little from its vertical position; the mercury will, by this act, receive such an impetus, as will force it up to the top of the tube, and make it strike the interior summit. If the blow thus given be of a hard and dry character, we may pronounce the vacuum to be good; but, if on the contrary, the blow sound dull and imperfect, we may then be sure that the space above the mercurial surface contains air. The writer has an excellent barometer, constructed by Schmalcalder, twenty-

five years ago, which still affords such indications of a perfect vacuum.

There are many other methods of filling barometer-tubes; but, as they are all more or less objectionable, we do not think it necessary to employ the student's time with their detail.

59. We have said (40) that the mercury in the tube exactly balances the atmospheric pressure on the mercury in the cup, in which the open end of the tube is inserted. This height, *a b*, Fig. 2, varies in this climate from about 28 to 31 inches. Now, the exact difference in this height, at any two periods, would accurately measure the difference in the atmospheric pressures, were it not that, whenever *a fall* occurs in the tube, *a rise* necessarily takes place in the cup, on account of the communication between the two. For instance, if the distance from *a* to *b* were 28 inches at one time, and 30 at another, it would not be strictly correct to estimate the increase in the pressure of the atmosphere at exactly two inches; for the level *b*, which is the zero of our scale of measurement, is *lower* at the latter than at the former observation, on account of more mercury having left the cup to ascend the tube. Hence it results, that although the two levels are two inches farther apart than before, yet the increase of atmospheric pressure is *less* than equivalent to two inches of mercury: it becomes necessary, therefore, to take the comparative areas of horizontal sections of the reservoir and of the tube, and to make an allowance for this circumstance in any deductions from observation.

Fig. 2.

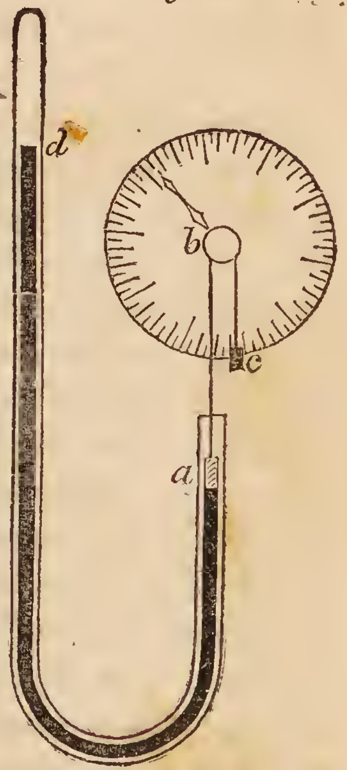


60. Whatever may be the causes which vary atmospheric pressure, and consequently vary the height of the mercurial column, it is desirable to attain as much accuracy as possible, in observing changes in that height; and various contrivances have been suggested for that purpose. In the common wheel-barometer (or weather-glass, as it is frequently termed), the tube, instead of terminating at the bottom in a cistern, is turned up again, fig. 3, as a siphon-tube, the shorter leg of which is open to the atmosphere. Now, a rise in the longer or closed tube is equivalent to a fall in the shorter one, and *vice versâ:* on the mercurial surface, therefore, in the shorter tube is placed a weight connected with a string passing over a pulley, on the other side of which this weight is balanced by another weight;

and the pulley is furnished with an index or hand, behind which is a circular face, (analogous to a clock-face,) which is graduated in any manner we please.

When, then, an increase of atmospheric pressure takes place, it depresses the mercury in the short tube, together with the weight a; this gives a small revolving motion to the pulley, and to the index attached thereto; and the number of degrees passed over by the index denotes the amount of the fall in the mercury. How far this apparatus deserves the name of a *weather-glass*, we will consider hereafter.

Fig. 3.



61. Soon after the invention of the barometer, many suggestions were made, for the purpose of increasing the delicacy of its indications, or for making it more convenient for use. The siphon-form has the advantage in the latter case, but its indications are not so delicate as those in Torricelli's; because a change of pressure, such as would make a difference of an inch in the height of the mercurial column of the latter, would show but half an inch of difference in the siphon. It is true, the two surfaces, a and d, would be an inch farther apart; but that inch would be compounded of a rise of half an inch at one surface, and a corresponding fall at the other,—the two parts of the tube being the same in diameter. Our unit of measure, therefore, becomes twice as great, and necessarily decreases in utility.

It was then proposed that a siphon-arrangement should be partly filled with mercury, and partly with water or oil, which, being lighter than mercury, would show a greater rise and fall with any given change of pressure. But it was found that air and vapour escaped from the oil into the vacuum more than when mercury alone was used; and that when *water* formed any part of the apparatus, the attraction between it and glass always caused some to cling to the latter, when a fall in the tube occurred. These objections were found to be more than a counterbalance to any advantages derivable from the more extensive rise and fall.

62. As an inclined line between two different heights is longer than a vertical line, it has been proposed to make the tube *oblique*, so that any vertical rise and fall in the mercury

should be indicated by a somewhat longer path; but increase of friction, and other causes, render this not very available; and it is a remarkable circumstance in the history of the barometer, that the one first constructed by Torricelli possesses, on the whole, more useful properties, and fewer defects, than any subsequently proposed. We could, perhaps, scarcely name another instrument of which the same could be said. There have, indeed, been others proposed, of which the *principle* is decidedly better, but requiring a degree of mechanical nicety in the construction such as we have no chance of obtaining.

Some modifications have been adopted for particular purposes,—for instance, one by Mairan, in which the tube is less than 28 inches long, and in which, consequently, no vacuum can exist until the atmosphere is reduced to great rarity. This is used to denote the degree of exhaustion produced by the air-pump in a receiver.

63. The superior attraction between mercury and other metals to that existing between mercury and glass (indeed, it is said that no attraction exists between the two latter, but, on the contrary, a repulsion,) has been taken advantage of to keep the lower level of the Torricellian column always at the same height. The cistern at *b*, fig. 2, is closed at the top, excepting a small space round the tube, with a cover, which is fitted on when the mercury in the cistern is at the lowest, and with such a slight degree of pressure as will force a small quantity up through the open space, which will form a liquid mound round the base of the tube. Now, when a decrease of atmospheric pressure causes a descent in the tube, an additional portion of mercury exudes from the open space; but the repulsion between it and the glass prevents it from climbing, as it were, up the outside of the tube, but it spreads out laterally over the cover of the cistern. Thus this little liquid mound retains the same elevation during the rise and fall in the tube, and its surface is made the zero of the scale of vertical measurement.

This same object (the maintaining of a constant level for the zero of the scale,) is likewise attained by an ingenious contrivance of Fortin's, in which the lower level of the mercury is, at each observation, brought into coincidence with the zero of the scale by means of a screw which elevates or depresses the cistern containing it. We shall shortly speak of a similar contrivance.

64. There are considerations connected with the comparative compression of different liquids by the same force, which have led to the construction of a *water-barometer*, with the hope that its greater range of rise and fall would measure more

minute changes of pressure; but such a barometer, necessarily 33 feet long, is out of the range of common experiment. There is, however, a very capital one in the Royal Institution, constructed by Professor Daniell; and another at the College in Edinburgh, constructed by Mr. Adie.

65. At the Cambridge meeting of the British Association in 1833, a new barometer by Mr. Snow Harris, was described. The tube of this instrument is of half an inch bore, bent in a siphon-form at one end; and at the other expanded into a flattened spheroidal bulb, whose diameter is 4 inches. The straight part of the tube, exclusive of the bulb, is 32 inches; inclusive of the bulb, 34 inches: and the recurved end is bent twice at right angles, so as to project from the tube 3 inches, and rise parallel thereto $7\frac{1}{2}$ inches. The tube, with the bulb uppermost, is attached to a frame; and the quantity of mercury is so adjusted that at mean pressure the upper level is at the widest part of the bulb, and the lower near the middle of the shorter leg.

A circle of brass, divided into 1000 degrees, is fixed to the front of a light copper case, having a glass front and back; the centre of which circle is placed just over the orifice of the glass tube. A small brass frame is fixed to the circle behind, so as to carry a light axis bearing two pulleys. The extremities of this axis form extremely fine pivots, which are set in small jewels; the front one projecting forwards so as to carry a light index of straw, sustained on a small brass ring at the end of the axis, like the hand of a watch. A small cone of glass is suspended from each of the pulleys by a silk thread; that which is rather the heavier of the two resting on the mercury in the recurved tube, and the other hanging freely outside, so as nearly to counterbalance the other. By these means the slightest elevation or depression of the mercury affects the conical float resting on it, with much greater facility and delicacy than in the wheel-barometer which we before described. The pulleys measure about an inch in circumference; so that if the mercury should move an inch, the index would be carried round the brass circle; and hence it is that one division or degree thereon corresponds to $\frac{1}{1000}$th of an inch, a correction being made for the difference of diameter between the tube and the bulb.

It will be seen that the principle of such a barometer is the same as that of Hooke's Wheel-Barometer; but the construction is infinitely more delicate in every respect. The preparation of the mercury, the mode of filling the tube, &c., are all so carefully attended to, that a barometer on this construc-

tion, when compared with the standard barometers at Paris and London, was found to give exceedingly accurate results.

66. The late Dr. Wollaston devised a barometer, which he termed a *Differential* Barometer. It was originally contrived with the view of determining the force of ascent of heated air in chimneys; but as its construction admits of much sensibility, it may be applied in other ways. A glass tube of narrow bore, being bent into the form of a siphon, of which the legs are parallel, is fixed at its two ends into two cisterns, each about two inches in diameter. One of these cisterns is closed all round, except where a small horizontal pipe springs from the top of one side; and the other cistern remains open. The lower or bent portion of the siphon-tube is filled with water, or other fluid, to the height of two or three inches; while the remaining parts of the tube, and part of the cisterns, are filled with oil, care being taken to bring the surface of the water in both legs to the same level, by equalising the oil above them. If now the horizontal pipe be applied to the key-hole of a door, or to any similar perforation in a partition between portions of the atmosphere in which the pressure is unequal, the water in the corresponding half of the instrument will be depressed, while it is raised in the opposite one; until the excess of weight in the higher column will just balance the external force resulting from the inequality of the atmospheric pressure upon the surface of oil in both cisterns. This, however, is equal only to the difference between the weight of the column of water pressing on one side, and that of an equal column of oil which occupies the same length of tube on the other side; which difference depends upon the relative specific gravities of the two fluids; which in the case of olive oil and water is about $\frac{1}{11}$th of the weight of the water elevated.

67. Professor Miller has recently devised a barometer, which consists of two tubes, of equal diameter, a little longer than the greatest height and greatest range of the barometric column respectively, terminating in a small cistern, the bottom of which can be elevated or depressed by a screw. The long tube is bent so that the upper part (which is closed at the end, and has a fine point of glass or steel fixed in its axis,) may coincide with the prolongation of the short tube, which is open at the end. A graduated scale slides along a vernier attached to the frame of the instrument, in such a manner that a steel point fixed to the lower end of the scale may move in the axis of the short tube. When an observation is to be made, the bottom of the cistern must be elevated or depressed, till the

surface of the mercury in the long tube touches the fixed point therein; the moveable point on the scale being then brought down till it touches the surface of the mercury in the short tube, the height of the barometic column is indicated by the division of the scale opposite to zero on the vernier.

68. The barometer being an instrument which (as we shall hereafter show) has frequently to be conveyed from one station to another, many plans have been devised to make it more portable than in its common form. We will describe two or three of such contrivances.

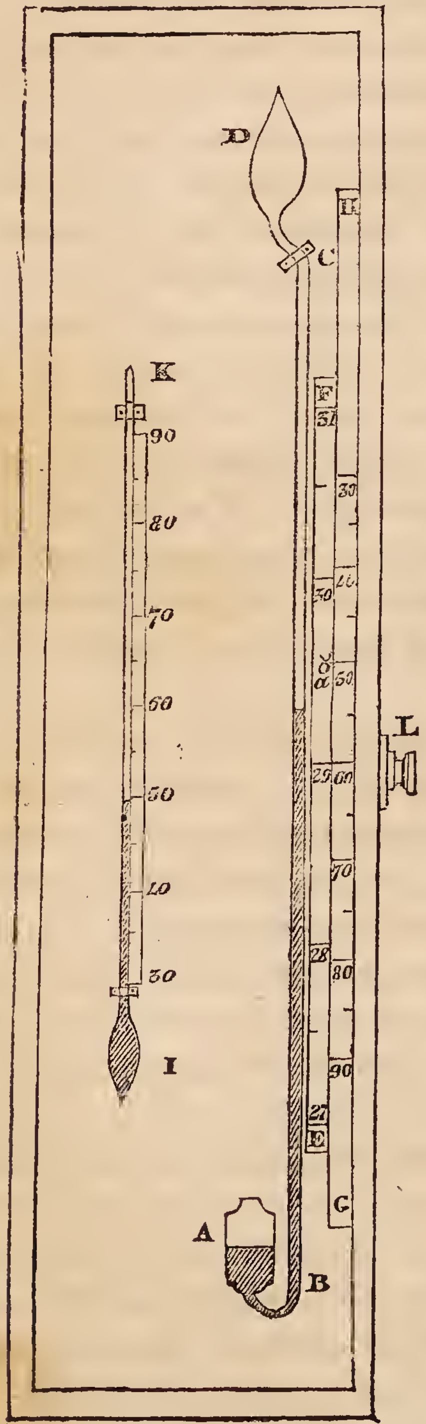
Troughton's Mountain-Barometer consists of a brass box or cylinder, which encloses the cistern containing the mercury. Two slits or apertures are made in the exterior cylinder, exactly opposite to each other; by means of which the observer can see through the cylinder from one side to the other, and likewise through the bottom part of the tube of mercury, at the point where the zero of the scale commences. At the bottom of the cylinder, is placed a screw, which adjusts the level of the mercury in the cistern to the zero of the scale, before each observation. The screw likewise forces the mercury up to the top of the tube, and prevents its oscillations when the instrument is being carried about. The upper part of the scale is finely graduated, the indications of which are rendered still more minute by means of a Vernier (for the principle of which we refer to the article "Vernier"). The indications are, by these means, so delicate that the five-hundredth of an inch can be estimated. At the top of the instrument a screw adjusts the vernier to the proper position on the scale, before each observation. The glass cylinder containing the mercury is $2\frac{1}{2}$ inches high, and the same in diameter. A thermometer is attached to the lower part of the tube, so that the temperature at the time of observation can be taken. When not in use the tube is lowered and enclosed between three legs, which act as a support to the instrument during an observation, and fold into a compact form when not in use.

69. Mr. Adie, of Edinburgh, has constructed a portable barometer very similar to that of Troughton; but differing from it in some respects. The ball of the attached thermometer is made of a piece of the barometer-tube about an inch and a half in length; and bent back so as to lie parallel with the tube of the barometer. The cistern is made of two circular pieces of wood connected by leather. Two concentric screws work in the bottom of the external brass cover; the outer one being to raise the whole bottom of the cistern, so as to fill the tube with

mercury for safety in carriage; while the inner screw adjusts the level of the mercury in the cistern to zero.

70. Another instrument has been constructed by Mr. Adie, which acts as a portable barometer. He calls it a *Sympiesometer**; and its principle consists in measuring the weight of the atmosphere by the compression of a gaseous column. It consists of a glass tube, A B C D, fig. 4, about 18 inches long and three quarters of an inch diameter; terminated above by a bulb, D, and having the lower extremity bent upwards and expanded into a cistern, A, which is open at the top. The bulb, D, being filled with hydrogen, and a part of the cistern, A, and of the tube, B C, containing almond-oil, coloured with anchusa root; the enclosed gas, by changing its bulk according to the pressure of the atmosphere on the oil in the cistern, A, produces a corresponding elevation or depression of the oil in the tube, thereby indicating the variations in the weight of the atmosphere. The scale for measuring these changes is determined by placing the instrument along with an accurate barometer and thermometer; in an apparatus where the air may be condensed or rarefied, so as to make the barometer stand at 27, 28, 29, 30, or any other given number of inches. The different heights of the oil in the tube of the sympiesometer corresponding to these marks, being laid down on the scale E F, and the space between each mark being divided into an hundred parts, these smaller divisions correspond with hundredths of an inch on the scale of the mercurial barometer. To correct the error that would arise from the change produced in the gas by a change of temperature, the principal scale, E F, is made to slide upon

Fig. 4.



* Compounded from the Greek; *a measurer by* or *of compression.*

another scale, G H, so graduated as to represent that change, and corresponding to the degrees of a common thermometer, I K, attached to the instrument. In this state, the rule for using the instrument is simply to observe the temperature by the thermometer, I K, and to set the index (*a*) which is upon the sliding scale, E F, opposite to the degree of temperature upon the fixed scale, G H: then the height of the oil, as indicated by the sliding scale, will be the pressure of the air required. The sliding scale, E F, is moved by means of a handle or knob, L.

71. The motion of a ship at sea renders it difficult to determine the height of the mercurial column of a barometer: different modes of construction, therefore have been adopted for *Marine* Barometers. Professor Blondeau, of Brest, constructed a marine barometer of an iron tube intended for a musket-barrel, by bending it in the middle into a siphon-form, with the ends uppermost. The lower end of this tube was tapered to a narrow bore, through which passed a light float resting on the surface of the mercury in the shorter leg of the siphon. An index was connected with the float, which passed in front of a graduated scale attached to the longer leg of the siphon. As the mercury rose or fell in obedience to variations of atmospheric pressure, the float and the index shared in those variations of position, and thus indicated on the scale the pressure of the atmosphere.

72. Gay-Lussac has proposed a convenient barometer, which may be enclosed in a walking-stick. It consists of a siphon-tube containing mercury, and hermetically sealed at both ends, having, at about an inch from the recurved part, a very fine capillary hole, by which the external air is permitted to act upon the mercury within. The lower portion of the principal branch has its bore contracted to less than one-tenth of an inch, to prevent the column of mercury from dividing in the act of turning the instrument.

73. Mercury and glass, in common with all other bodies, expand by heat; and therefore a rise in the barometric mercury may not be absolutely due to increased pressure; for a rise in temperature in the surrounding air, independent of an increase in its pressure, will expand, and therefore elevate, the mercury; and not only so, but the graduated scale, which is generally attached to a barometer-tube, expands also. But, unless an equal degree of expansion take place in all the parts of the instrument with a given increase of temperature, a discrepancy in the result will occur. Now, it is found that solid metals (such as the scale is made of,) and mercury and glass, expand

unequally, and it is necessary to apply mathematical formulæ to correct the difference: for common purposes, however, the fact that mercury expands much more than the metal of the scale, has led to the neglect of the expansion of the latter.

74. Another circumstance is the effect of capillarity, or the manifestation of attraction or repulsion between a solid and a fluid, when the latter is contained within a very small tube of the former. Now, if we employed water as a balance to the atmospheric pressure, capillary attraction would raise the water somewhat higher in the tube than would be due to the pressure alone; but as the bias between mercury and glass is of a repulsive nature, the mercurial column is somewhat *lower* than it should be; corrections for this effect have likewise been deduced mathematically.

Much uncertainty exists as to the real nature of the causes which render the surface of the mercury in the barometer-tube *convex* when the mercury is rising, and *concave* when it is falling. Some have considered that the concave form, while the mercury is sinking, indicates an attraction rather than a repulsion between the glass and the mercury; while others state that, if the mercury were absolutely pure, and every trace, every atom, of moisture and air removed both from the mercury and the inside of the tube, the surface would be *always* convex; the concavity being due to the presence of particles of bodies which have an attraction for glass. This subject requires and deserves further investigation.

75. The last source of error which we will mention, is the existence of mercurial vapour in what we have termed *the vacuum.* It has been stated (22) that evaporation goes on from any fluid until an atmosphere of the same kind exists above it, the tension of which prevents more from forming. There is no possibility of getting rid of this mercurial atmosphere; and therefore, the smaller the excess of the tubes length above that of the mercurial column, the better.

Section III.—On the Relation between the Barometer and various Meteorological Agents.

76. Having treated of the contrivances for noting the amount of change in the pressure of the atmosphere, we will now state some of the causes which produce such endless fluctuations therein.

If we take $14\frac{1}{2}$ pounds as the average atmospheric pressure on a square inch at the earth's surface, any diminution of that

pressure must arise from a diminution in the number of aërial particles in a given space,—that being our idea of the word *expansion*. Now this is brought about mainly by heat. The solar rays heat the air, both by passing through it, and by being reflected from the earth's surface; but, as the latter heating process is much more efficient than the former, the lowest stratum of the atmosphere becomes more heated than those which are higher:—the consequent expansion renders it specifically lighter than that next above it:—and (by virtue of that rarity,) it ascends to a more rarefied stratum. Now, if every part of the globe shared equally and simultaneously the sun's rays, the same formation and ascension of expanded and lightened air would take place at every part:—during the day, the whole atmosphere would be rarefied,—would reach to a greater height above the earth,—and (as night came on,) would be gradually condensed again, and fall nearer the earth; and these reciprocating changes would occur every day.

77. But as it is, the sun's rays being vertical at only one spot at a time, and more and more oblique as we recede from that spot, every gradation of temperature is experienced from 120° above, to 50° below, zero. Now, let us suppose two belts on the earth's surface, one situated vertically under the sun's path, and the other receiving his rays obliquely, and therefore with less heating effect. The air in the first belt is more expanded by heat than that in the second:—greater rarefaction exists in the one than in the other:—and as gaseous as well as aqueous fluids always tend to an equality in density, the air in the colder belt rushes towards the warmer.

This motion is the grand and prolific source of *wind*. The equatorial regions being constantly more heated than the polar, a current of cold condensed air is regularly flowing from the latter to the former, to fill up the partial vacuum occasioned by the greater expansion and rarity of air at that point. It might be supposed that, as the equatorial belt not only contains its own air, but is constantly receiving fresh accessions from the polar region, an overpowering weight of air would accumulate at that part; but this is prevented by a counter-current in the higher regions of the atmosphere. An elevated stream of warm air is constantly flowing from the equator towards the poles, to supply the place of that which flows from the latter towards the former near the earth's surface.

78. This rush of air from the poles to the equator would therefore engender a constant north wind in the northern hemisphere, and a constant south wind in the southern hemisphere;

and the circumstance that we do not find it so, is no proof of the incorrectness of the conclusion; for such *would* be the case, if the earth did not revolve on its axis. This revolution changes the direction of the stream of air, thus:—The atmosphere revolves with the earth; and as every part of the earth's surface revolves round the axis once in twenty-four hours, the parts nearer the poles must obviously describe a smaller circle than those at the equator, and must therefore move with a less velocity; and as the atmosphere shares the velocity of the part of the earth over which it is vertical, the polar and temperate portions move more slowly round the axis than the equatorial portion. The stream of cold air, therefore, which rushes to the equatorial regions, is a slow-moving zone, the transverse approach of which towards the zone which is moving more quickly, gives it the effect of an *oblique* approach; and it is consequently found, that north of the equator there is a wind (or stream of air) constantly coming from the north-east to the equator, and at the south of it a south-east wind blowing towards the same boundary. These winds, from the dependance which may be placed upon them, and from their consequent value to navigation, are called the *trade-winds*, and extend about 30° on each side of the equator*.

These winds, however, maintain their regularity only in the open ocean. Where land breaks the continuity of liquid surface, great changes are produced; but the most remarkable effects exist in the Indian Ocean.

79. If we draw a line from the Cape of Good Hope, in Africa, to Swan River, in Australia, we shall thus have the extreme southern boundary of the trade-winds; and were no interruption offered by the neighbouring continents, the south-east trade-wind would extend northward to the parallel of Zanguebar, in Africa, and Sumatra, in the Indian Archipelago,—north of which line would blow the north-east trade-wind. But a remarkable change is effected, which shows itself thus:—The 3rd degree of south latitude is a boundary between distinct winds;—from that boundary northward to the continent of Hindostan, a north-east wind blows from October to April, and a south-west from April to October; while from the same

* It has been generally supposed that the trade-winds are more easterly, the nearer we approach the equator; but Captain Basil Hall has ascertained the contrary to be the fact, and has well explained it by referring to the figure of the earth. The 20th parallel of latitude, for instance, does not differ from the equator in circuit so much as the 40th differs from the 20th, and thus the retardation which gives the easterly tendency is not so great near the equator as at a further distance.

boundary to the 10th degree of south latitude, a north-west wind blows from October to April, and a south-east from April to October. These winds are called *monsoons**, and on the eastern side of the globe originate with the trade-winds, of which they are a species, produced by the diversity of continent and islands, seas and gulfs, in this part of the world. It appears likewise that the sun's presence exerts great influence in thus modifying the trade-winds, and producing the westerly winds; —and the proportional distribution of land and water suggests the following considerations:—Water, from its transparency, admits more rays of light and heat to pass through it than it reflects from its surface; but with solid ground it is just the reverse. During our northern summer, therefore, the sandy plains of India (which are wholly within the northern hemisphere) become greatly heated, whereby the air above them is expanded and rarefied more than that which hovers over the ocean; the consequence of which is, that a stream of cold air flows from the sea towards the land; which is the cause of the south-western monsoon. But when, at the end of September, the sun passes the equator and enters the southern hemisphere, India gradually loses its excessive heat, and the land and sea becoming more equable, the north-east trade-wind resumes its usual course.

80. But now a corresponding change takes place in the southern hemisphere:—the vast continent of Australia, which is wholly within the southern hemisphere, exerts the same disturbing force on the incumbent air as the hot plains of India exerted six months before:—this brings on the north-western monsoon; at the expiration of which the south-east trade wind blows as before.

81. Europe is too remote from these regions to share much of these effects; but such effects are important to our purpose, as showing the vast influence which the relative distribution of land and water has upon the equilibrium of the atmosphere. Thus, on sea coasts in warm climates, a breeze is blowing *towards* the land during the day, and *from* the land during the night. This arises from the circumstance that the sea suffers but little change of temperature during the twenty-four hours, being generally colder than the land during the day, and warmer during the night:—this determines the relative ex-

* The term *monsoon*, or, according to the Persian, *mousum*, implies "*seasons*;" and is so used in the Malayan *moossin*, and other dialects of the East. The *breaking-up of the monsoons*, or periodical change in the direction of these winds, divides the Indian year into two *seasons*.

pansion of the air over each, and the consequent direction of the wind.

These are the only circumstances, under which the direction of a wind can be depended on with tolerable accuracy. The "fickleness of the wind" has become a proverb, and we are yet unable to fix the causes of the changes in the temperate winds. There appears, however, to be *a general* tendency towards south-west winds in the northern hemisphere, and north-west in the southern. This probably arises from the upper currents flowing from the warm to the colder regions;—they approach the earth gradually as they proceed, and thus come to be considered as the prevailing winds.

82. The aspect of a country, with respect to mountain-chains, &c. is very influential on winds; thus:—Supposing a general south-west wind to blow from the ocean to a country which had a chain of mountains running from north-west to south-east; the northern part of that country might scarcely feel the effects of the wind in question, from the intervention of the mountain-range. Thus, likewise, in a smaller degree, every change in the elevation of the country exerts an influence on the direction and intensity of the wind.

83. The tendency to the equalization of density and of heat in the atmosphere, happily subdues in some measure the extreme cold of the frigid and the scorching heat of the torrid zones; but still a necessarily warmer state of the atmosphere constantly exists at and near the equator than at any other part; and this brings us to another important branch of our subject—the increased capacity of air, when at a high temperature, for aqueous vapour. In what way heat insinuates itself among the particles of bodies is uncertain; but the effect is to put those particles further asunder. It has been stated (21) that, when a fluid is heated, evaporation is gradually increased; but its free and rapid escape in the manner which we call *boiling*, depends altogether on the amount of *steam*-pressure contained in the atmosphere. At the usual state of the air, water boils at 212°—in a vacuum at 72°; and by greatly condensing the pressure on its surface, 400° have been attained before boiling commenced.

84. This being the direct effect of heat, we can easily understand that the great bodies of water in hot climates are constantly sending forth accessions to the atmosphere, in the shape of aqueous vapour. It is thus that the immense basin of the Mediterranean is believed to maintain a constant level. The mighty bodies of water, which the Nile and the great European

rivers pour into its bosom, would overflow its shores, were it not for this slow but constant evaporation; for it has been found that no current flows through the Straits of Gibraltar from the Mediterranean to the Atlantic; but, on the contrary, a current flows in the opposite direction.

85. The same takes place to a smaller extent in other climates, and hence arises the question, "What becomes of this body of aqueous vapour?" It is wafted, together with the warm air by which it is surrounded, to colder regions; and, there becoming condensed, has no longer the rarity, or tenuity, requisite to retain the invisible, aërial form. When the cold, from any sudden change of elevation or of density, is increased, the vapour falls to the earth as rain, snow, or hail, according to the temperature of the space through which it has to fall. It is conjectured that the overflowing of the Nile is thus brought about. The product of the great evaporation from the Mediterranean and Red Sea is carried, in the form of clouds, by wind into central Africa, which meeting with the elevated Mountains of the Moon in Abyssinia, are condensed into water by contact with the cold summits, and descend in a sheet of rain, such as Europe is never subjected to; and thus the sources of the Nile, after the hot season, become enormously distended.

86. Now the winds of the Indian Ocean, and the rains of central Africa, being copied in miniature at every part of the earth, we need no longer wonder at the continual variation in the pressure of the atmosphere, which supports the mercurial column in the barometer. Should a body of air, highly saturated with aqueous vapour, be from any cause removed to a colder altitude, its steam becomes precipitated in the form of cloud, and ultimately in that of rain; and an immediate disturbance of the equilibrium of the atmosphere is the result, which is followed by a variation in the height of the barometer.

87. But we must here be understood as not affirming that the rise or fall of the barometric mercury is an exact index of the varying proportion of the aqueous vapour contained in the atmosphere. The sources of the increased pressure are various, and difficult to assign with precision. For instance, it has been found at Paris, by many thousands of accurate observations, that the mercury stands higher at that place during a north-east wind than during any other, and lowest during a north-west;—that it is higher at nine in the evening than at three in the afternoon, and still higher at nine in the morning;—and that it is higher in February and lower in October than in any other months of the year. We must, therefore, guard against

supposing that the hottest month, or the hottest time of the day (although it may give the greatest amount of evaporation,) will give the minimum of pressure*.

88. Few subjects have led to more theories than the production of rain. Many have believed that it results almost wholly from electrical causes. This idea is supported by observations made in various ways upon the electrical states of clouds and rain. Dr. Hutton's ingenious theory is grounded on the increased capacity of heat for aqueous vapour, at a higher temperature. But he supposes that that capacity does not increase in the same ratio as the temperature of the air increases. For example:—the capacity for aqueous vapour of a body of air at 55° Fahr., is not a mean between the capacity at 50° and at 60°, but somewhat *lower* than the mean.

Aqueous vapour at 40°, has an elastic tension or force of 0·263 inches in weight of mercury, and at 60° a tension of 0·524. If, therefore, two masses of air—the one at 40° and the other at 60°—being both saturated with moisture, be mixed together, the compound will take a mean temperature of 50°; but the tension of steam at 50° is 0·375, while the mean of the forces at 40° and 60° is 0·3935. The tension is therefore greater than the temperature can contend against, and a portion becomes condensed in the form of rain.

89. Electricity. This, which we have just alluded to, is a mysterious and powerful agent in atmospheric results. It is not our intention to enter far into electric science. We may, state, however, that the principal atmospheric effects produced through electrical agency depend on the simple circumstance, that the aqueous particles found in the atmosphere do conduct electricity, while its constituent gases do not conduct electricity.

In electricity, we are accustomed to say that the dry air is an insulator; or that, if an electrified body be surrounded by dry air, the electric charge will not leave it. Now, this expression, *dry air*, simply means air deprived of the *steam-atmosphere*; and though we can never completely get such a state of the air, yet the finer and warmer is the weather, the more expanded is the steam-atmosphere, and the less likely to appear in the watery form: so that there is reason to believe, that if the

* The influence which common parlance exerts on the acquisition of correct notions on scientific subjects, has often an unfortunate tendency. Thus, when we say in dull weather, "the day is heavy,"—"the air is thick and heavy," it is not generally supposed that the air is really *lighter* than on a fine day; but the fall of the barometer indicates that this is the fact.

steam-atmosphere could maintain a high temperature, and a consequent high tension, it would have the insulating properties of the dry gases, for electrical experiments succeed exactly in proportion to the warmth and dryness of the apartment in which they are conducted; while on a damp, misty day, when the steam-atmosphere may almost be said to be in a state of transition from air to water, the failure of the same experiments is an almost certain consequence.

90. What may be the conditions of equilibrium in the electrical state of the atmosphere, are not yet determined; but it is found that that equilibrium seldom exists in a complete degree. If a kite be elevated into the air,—through the string of which a metallic wire passes, connected at the lower extremity with an electroscope,—it is generally found, even in the finest weather, that the latter is slightly affected; thus indicating the non-existence of electric equilibrium in the stratum of air in which the kite is situated. This indication becomes stronger, as the kite is more elevated, and generally denotes *positive* electricity in the air—indeed, invariably so in fine weather; it is stronger in winter than in summer, and in the forenoon, than in any other part of the day.

91. When, however, the atmosphere is cloudy, and the clouds appear to be moving about in different directions, and in an uncertain manner, the electric excitation is much increased, and changes from positive to negative, and *vice versâ*, with great frequency. The *negative* state is prevalent on the approach of any phenomenon connected with the condensation of aqueous vapour into the watery form, such as rain, hail, sleet, snow, fog, &c. This is followed by frequent alternation from positive to negative, which alternation rapidly increases if a thunder-storm be forthcoming.

92. It is not improbable that the carbonic acid atmosphere to which we have before alluded, (22) has great influence on the determination of the condition or kind of electricity which is manifest at any given part of the atmosphere; for if a room be filled with the respired breath of several persons, it is in a state of *negative* electricity.

Setting aside for a moment the effect of the amount of vapour in the air, it is found that in proportion as the latter is rarefied, the conducting power which it exerts on electricity is increased; and we can from this understand how much the variations in density which are produced in the air by causes already mentioned, are likely to disturb the electrical equilibrium of its particles. This disturbance, by causing the rapid transfer of

electricity from large masses of air which are over-saturated with it, to others which have less than their proper amount, condenses the air in some parts more than in other, and by varying its pressure, causes fluctuations in the mercurial height of the barometer.

93. It will thus be seen that temperature, electrical equilibrium, retention or deposition of aqueous vapour, elevation of position, and various other considerations, take part in the determination of the height of the barometric mercury. But, as was before observed, what may be the relative proportions in which these elements are concerned in the production of any given state of the atmosphere, we have not, in the present state of our knowledge, the means of deciding: the average, however, of a large number of observations made by different persons, at different times, and in different places, has furnished rules which deserve some degree of reliance, although far from implicit.

94. Rules for observing the Barometer.—A fall in the mercury generally indicates approaching rain, snow, high winds, or thunder. A very high wind, whether accompanied by rain or not, is, perhaps, connected with the lowest state of the mercury. In the temperate latitudes, the rise and fall are more extensive than near the poles, or the equator. In England, as well as in France, a north-east wind is more conducive to a high state of the barometer than any other.

When the mercury either rises or falls pretty steadily for two or three days together, it is generally found that rather a long continuance of settled weather will follow—rainy in the latter case, and fine and dry in the former; by the same rule, frequent fluctuations in its height are found incompatible with an equable state of the weather.

95. Such are the principal rules for observation; but the dependance which is commonly placed on the wheel-barometer, or weather-glass, is much more than it deserves. The dial, on which the index moves, is graduated and laid out into a number of divisions, at different parts of which, the words, "set fair," "rain," "much rain," &c., are engraved. Now, the phenomenon of rain does not depend on a given, *fixed*, pressure of the air, but on comparative *changes* which occur in that pressure; when, therefore, we see at a certain number of inches, and hundredths of an inch, the words "much rain," we might conclude that was as long as the index at that part, rain would fall, while at the height marked "set fair," rain could not possibly occur: this, however, is not found to be the case: and

a vague and general power of prophecy is all that can be obtained by this form of the instrument.

96. A writer in the *Edinburgh Cyclop.* states, that the greatest elevation of the mercury which he had ever observed, was on the 30th of Nov. 1816, and that this took place during a westerly wind. On the morning of that day, a barometer, 185 feet above the level of the sea, stood at 30·64 inches, and in the evening, at 30·602; corresponding respectively to 30·825, and 30·787, on the sea-shore. The greatest depression which he had seen in that country for many years, was on the 5th of March, 1818, with a south-west wind. The weather, for a considerable time before, had been stormy and unsettled, with hurricanes of snow and rain from the west. On the evening of the 4th, the wind shifted to the east, the barometer at the same time sinking rapidly. During the night, the wind got round again to the south-west, and at 8, on the morning of the 5th, the barometer stood at 27·97; corresponding to 28·155, at the level of the sea. On the same night, the tide rose unusually high in the river Tay, though it was only the first of the spring-tides, being two days before the new moon; and at the time that these phenomena were observed in lat. 56° 24′, a violent hurricane was experienced at London, and various other places in the south of England.

97. The information as to the influence of the moon on the barometer is contradictory and vague. Mr. Howard has stated, that, on an average of ten years, he has found that the barometer is depressed $\frac{1}{10}$th of an inch while the moon is passing from the quarter to the full, or to the new; and elevated in the same proportion during the return to the quarters. The experience of other observers, however, has given results very little in accordance with these.

98. The oscillations of the barometer, or the small but frequent changes in its height, have engaged much attention, with the view of determining their causes. Long continued observations must, however, be made, before we shall arrive at a correct knowledge of the laws, which govern those changes.

The oscillations are generally measured by *millimétres*, each of which equals 0·03937 English inches. The oscillations are called *horary**, when they are observed for the different hours of the same day. M. Bouvard has recently investigated this subject. He found that, at the equator, the amount is proportional simply to the temperature (on the centigrade scale) of the period, during which, the oscillations are observed at the given spot;—

* From the Latin *hora*, an hour.

the oscillation and temperature at the level of the sea being unity; and that away from the equator, the same law must be modified by the latitude. Professor Forbes, has, however, expressed doubts of the correctness of this law.

99. The last-named philosopher has found, from a course of four years' observations at Edinburgh, that, in that latitude, the mean annual oscillation between 10, A.M., and 4, P.M., is 0·0106 inches; or 0·27 millimétres:—that the hours of maximum oscillation are farther from noon in spring and autumn, than in summer and winter:—and that the amount of oscillation in both the diurnal periods diminishes regularly through the seasons, from spring to winter.

100. Mr. Snow Harris has found that the mean force of the wind is greater at the period of afternoon minimum of the barometer, than at either the morning or the evening maximum. At Paris, it has been found that the height of the barometer,—other things being equal,—is seven millimétres greater during a north-east wind, than during a south or south-west. At London, the excess has been stated at eight millimétres.

101. The experiments of Dr. Prout, to which we have before alluded, (13) elicited a result which is worthy of our notice. His experiments on the weight of a given bulk of atmospheric air, were made during a period of about three months. At about the middle of that period, the air weighed heavier than it had done previously; and continued, during the whole of the subsequent observations, to be above the mean weight. Precisely at that period, the epidemic cholera first made its appearance at London, where the experiments were made. The saliva, and the other secretions, of nearly all persons on whom experiments were made during that spring and summer, were found to be unusually acid; and Dr. Prout thinks it not an unreasonable conjecture, that the same cause which produced the increase of weight in the air was in some way connected with the arrival of the cholera at that period.

102. Until the laws, which regulate the changes in the state of the atmosphere, are better understood, it would be premature to attempt to generalize from the facts just given. More experiments and observations must be made before that can be done satisfactorily. We pass on, therefore, to consider the application of the barometer to the measurement of heights.

103. MEASUREMENT OF HEIGHTS. As each stratum of air has to bear a greater pressure than the stratum next above it, and as its pressing force on other bodies is dependent on the force with which itself is pressed, the barometric column

encounters a decreasing pressure in proportion as we ascend from the earth's surface. The manner in which this circumstance is rendered available for the measurement of the altitude of elevated positions or objects, we will now briefly detail.

No sooner had Pascal found his anticipations respecting the fall of the mercury, on ascending from the earth's surface, to be correct, than he at once conceived the idea of applying that principle to the measurement of heights. To do this, it was first of all, necessary to determine the comparative state and nature of the air at different elevations. Here Pascal committed a capital error: he supposed that the atmosphere was of equal density throughout,—and that, as a column of the atmosphere supported about thirty inches in height of mercury, he would only have to observe the depression of the mercury on ascending a mountain, and then to ascertain the height of the mountain by comparing the relative weights of mercury and air: which have been since determined by Biot and Arago to be 10,466 to 1.

104. This was soon found to be incorrect; and Halley demonstrated that the density of the air decreases in a geometrical ratio, while the elevation increases in an arithmetical ratio: that is, if at a certain height the density were half of that at the earth's surface, at twice the height it would be $\frac{1}{4}$, at thrice $\frac{1}{8}$, and so on; and it having likewise been determined about that period, that the pressure of aërial fluids is exactly proportional to their density, (a very important and beautiful law,) Halley clearly showed that the ratio of decrease in the pressure was different from that of the increase in the heights.

105. Now the relation between an arithmetical and a geometrical progression is exactly that which subsists between a series of logarithms and their natural numbers; and Halley conceived the happy idea of applying a common table of logarithms to the solution of these questions. But, it was necessary to determine a unit of his two series; and this he did by computing that the height at which the atmospheric pressure is exactly half that at the earth's surface, must be about $3\frac{1}{2}$ miles. Hence, at the height of

m.	m.	m.	m.
$3\frac{1}{2}$	7	$10\frac{1}{2}$	14, &c.

the density of the atmosphere is

$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{16}$, &c.

Mathematical considerations, into which we cannot here enter, induced him to fix upon the number 62,170 as a constant multiplier, as follows: observe the height of the mercury at the

earth's surface, and then at the elevated station;—take the logarithms of those numbers, and subtract the smaller from the greater;—multiply the difference by 62,170, and the result is the height in English feet. This process has been found to give an exceedingly near approximation, especially in a temperate climate.

106. The latter half of the last century, however, was enriched by many valuable discoveries concerning the expansion of bodies by heat; and it was soon found that a correction for temperature was necessary in barometrical measurements. A splendid train of investigations occupied the attention of Bouguer, Bernouilli, De Luc, and Laplace; and the result was a formula which grappled with most of the difficulties of the question. To give some idea of the accuracy which De Luc brought into experiments on this subject, it will be sufficient to state, that *two* barometers, and *four* thermometers, were used in each experiment; the exact differences between their respective indications were rigorously noted; and then a series of computations was applied to each observation.

107. All these computations have been tabularly arranged by Oltmanns, in a convenient way for practice: but Professor Quetelet has given an easy mode, taken from De Luc, of attaining a very near approach to correctness. This mode, which was calculated for French toises*, when adapted to English feet, appears in the following form:—Multiply the difference of the logarithms of the two heights of the mercury by 63,946; the result is the elevation in English feet. Then correct for temperature, thus:—take the mean of the temperature at the two elevations; if that be 69·68° Fahrenheit, no correction is necessary; if above that, add $\frac{1}{215}$th to the whole height found, for each degree above 69·68°; if below, subtract the same quantity. For example:—Humboldt found that at the level of the sea, near the foot of Chimborazo, the barometer stood at exactly 30 inches; while at the summit of the mountain, it was only 14·85:—then the logarithm of 30·0 is 1·4771213, and the logarithm of 14·85 is 1·1717237: then subtracting

$$\begin{array}{r} 1{\cdot}4771213 \\ 1{\cdot}1717237 \\ \hline 0{\cdot}3053976 \end{array}$$

Multiply this by 63,946, which produces 19,529 for the number of feet of elevation. If then the mean temperature of the two

* The *toise* is 6·39495 English feet; or rather more than a *fathom*.

stations were 69·68°, we should have no correction to make for temperature. This is a near approximation; as the most careful calculation has given 19,332 as the real height, which was probably estimated for a lower temperature.

108. After the discovery of any principle in science, perhaps the most valuable step in its progress is the attempt to bring it within the range of popular application; it is then, when the field is tended and cultivated by a multiplicity of labourers, that the seed most rapidly germinates, and produces its wonted fruit. Actuated by the knowledge of this truth, Professor Leslie devised a mode of measuring heights, without the aid of logarithms; and thus placed the computation within the reach of all who knew the merest rudiments of arithmetic. His mode is this:—ascertain the exact barometic pressure at the base, and at the summit, of the elevation; and then institute the following proposition:—as the sum of the two pressures is to their difference, so is the constant number, 52,000 feet, to the answer required (in feet). For example, suppose the two pressures were 29·48 and 26·36—then

As 29·48 + 26·36 : 29·48 — 26·36 : : 52,000 feet : 2905·4 feet,

the answer required.

109. This mode has been found very applicable to the mean temperature of our climate, and for all heights under 5000 feet. It will, therefore, be available for all the elevations in Britain; and we would suggest this to such of our readers as possess facilities for visiting the hilly districts of Scotland, Cumberland, or Wales, as a very delightful source of scientific inquiry. The barometer should have a vernier for reading off hundredths of an inch, as a difference of one tenth of an inch, will indicate from 88 to 100 or 110 feet, according to the density or pressure.

It must be understood that *perfect* accuracy can never be depended on in these results; but a sufficiently near approximation, for most purposes, can be obtained.

110. Valuable as is the Barometer, as a means of determining the heights of elevated stations, there are yet many circumstances to be investigated, before such indications can be implicitly relied on. Thus, Von Buch has observed that the mean pressure of the atmosphere is greater at Paris than on the shores of the Baltic; although the latter are obviously at a less elevation than the former. Professor Forbes, in his valuable Report on Meteorology, has mentioned a circumstance which shows that the barometric pressure is influenced by the proximity of the ocean. Captain King, previous to a voyage to the Southern Ocean, compared his barometer with that kept at

Greenwich. He did this likewise at his return. Between those two periods, the indications of his barometer were observed five times a day for five months. The result gave as a mean height for the whole period, 29·462 inches, at an elevation of 5 feet above the level of the sea:—a pressure decidedly less than the mean pressure on land, at the same level.

111. Boiling-Points. Soon after Fahrenheit had invented the Thermometer which bears his name, it occurred to him that, as the temperature, which water obtains before it boils, is dependant on the pressure of the air above it, the boiling-point of water might be available for the measurement of heights, as the density decreases upwards. This principle was afterwards advantageously determined by Saussure, and has been subsequently simplified by the discovery that the boiling-point of water decreases in a geometrical ratio, nearly equivalent to the decrease of atmospheric density; and the following rule has been laid down, adapted to the centigrade-thermometer, in which the freezing and boiling-points of water are separated by a range of 100 degrees:—for every decrease of 1° Cent. in the boiling-point of water, reckon 1000 feet of elevation, if the temperature be at or about $5\frac{1}{2}°$ Cent. (or 42° Fahr.); but a slight correction is necessary for other temperatures, on account of change in the comparative density of the air. This correction is computed from the law that the air expands $\frac{1}{480}$th for every degree of Fahrenheit, or $\frac{1}{267}$th for every centigrade-degree; whereby its pressure becomes necessarily lessened. Centigrade-degrees can be easily converted into those of Fahrenheit, by remembering that one centigrade-degree is equal to 1·8° of Fahrenheit; or one degree of Fahrenheit is equal to 0·555 of centigrade-degrees.

112. The limits of our subject will not permit us to enter fully into the phenomena connected with the boiling-points of water; but it is found that very remarkable results are dependent on the determination of that point:—thus the nutritious principle, in many kinds of common animal and vegetable food, cannot be extracted at a lower temperature than 212°; so that those who live in very elevated regions, such as the plains of Mexico, &c., are deprived of many luxuries which their more fortunate, because less elevated neighbours, are capable of procuring.

This is particularly remarkable at the Hospice de St. Bernard, which is situated in one of the passes of the Alps, at an elevation of 8600 feet. There are many kinds of animal and vegetable food, which the monks cannot prepare by boiling, as water boils at 203 degrees at that elevation, which is an insufficient

heat for the purpose: hence that isolated little band,—situated at the boundary of the beautiful Swiss valleys on the north, and the rich plains of Savoy on the south,—seem, as it were, cut off from participating in many comforts; from the simple fact that they cannot make their boiling water as hot as that of their neighbours below.

It has been suggested by Dr. Arnott, that, probably, the peculiar flavour which London Porter possesses, when compared with other malt liquors, may be owing to the great depth of the vats in which the ingredients are prepared. It is probable that the water at the bottom or lower part of those vats, is at a higher temperature than 212°, when boiling, on account of the immense pressure of the superincumbent water; and that this higher temperature extracts properties from the vegetable ingredients for which water at 212° would not avail.

113. Barometric Light. In concluding this article we will briefly mention a phenomenon called *Barometric light*, which appears to be wholly of electric origin. If the mercury in a barometric tube be shaken, luminous indications may be observed, which in a darkened room are very striking. The friction between the mercury and the glass, uninfluenced by the presence of air, elicits electricity from the glass. A similar effect can be produced by placing a cup of mercury under the receiver of an air-pump. As the exhaustion proceeds, the mere shaking which results from the handle of the pump, by causing friction between the mercury and the cup, elicits a luminosity so decided, that the whole apparatus becomes visible in a darkened room.

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114. We have thus thrown together, in a popular form, the principal elements necessary for a right appreciation of the principles of that beautiful instrument, the barometer:—beautiful, whether viewed in connexion with the atmospheric phenomena upon which its action depends, or with reference to the impulse which its discovery gave to that burst of mind, which, in the sixteenth century, displayed itself in almost every country in Europe:—a time when men began rightly to perceive that the study of the Laws of Nature cannot be prosecuted by closet-reasoning, unless it be conducted hand in hand with experimental inquiry.

III.

THE HYDROMETER.

These roving mists, that constant now begin
To smoke along the hilly country, these,
With weightier rains, and melted Alpine snows,
The mountain-cisterns fill, those ample stores
Of water, scoop'd among the hollow rocks;
Whence gush the streams, the ceaseless fountains play,
And their unfailing wealth the rivers draw.—THOMSON.

1. THE young student in science is frequently led to suppose, that the division of the natural laws into distinct sciences is the work of Nature, instead of being merely the arbitrary distinctions which the philosopher has introduced for the convenience of classification and arrangement. When we hear of the science of Pneumatics, of Hydrostatics, and of Acoustics, for example, it is usual to consider these as separate branches of inquiry, which have no apparent connexion. But this view would be erroneous and inconsistent with that beautiful harmony, the result of adaptation the most perfect, which pervades all nature. Our knowledge is divided into separate portions, it is true, and to each portion it has been found convenient to attach a name; but the laws, which regulate pneumatics, apply also to hydrostatics; and acoustics could not exist as a science, if deprived of the aid of the other two. In short, it is for the convenience of study and of reference, that we divide and subdivide the natural laws, and place in one division one set of phenomena, and another set of phenomena in another division. That Nature does not recognise these distinctions, will appear obvious, from the fact, that not only is sound due to vibration; but that also light, heat, and electricity are, according to the most general and rational opinions, due to the same cause. On the subject of these conventional distinctions, Dr. Priestley, half a century ago, well observed:—"The objects of science are so multiplied, that it is high time to subdivide them. Thus the numerous branches of an overgrown family, in the patriarchal ages, found it necessary to separate; and the convenience of the whole, and the strength and increase of each branch, were pro-

moted by the separation." If this were true in the time of Priestley, how much more so is it at the present day, when the amount of scientific knowledge,—the inestimable result of the labours of so many inquirers in every part of the civilized world,—has so largely increased! Since Priestley's day, geology has changed its aspect from a mass of crude theories to a body of highly valuable facts. Again, electro-magnetism, electro-chemistry, and polarization of light, have all sprung up into sciences since the age of Priestley; and as they sprang up, so was it necessary to find a distinctive place for them in the catalogue of human knowledge. If, therefore, for the correct appreciation of scientific principles, it be desirable to consider all the sciences as so many tints of one splendid colour, it is equally desirable for practical study, that we should give to each tint a distinctive name proper to itself.

2. In commencing a description of another of those ingenious contrivances, by whose means man is assisted in his application of the unerring laws of Nature, it will not excite surprise that the same general principles which regulate the action of the barometer apply also to the hydrometer*:—the one measures the weight and pressure of the air; the other measures the density of liquid bodies;—and, as we began our former article with a description of the atmosphere whose pressure was to be measured, so shall we now, (as far as applies to our subject,) examine the properties of the waters, and of liquids generally, whose densities are to be measured, and also the relation between liquids and solids with respect to their comparative weights. The second part of our object will be devoted to a description of those contrivances by which the density of liquids is ascertained, together with their application in science and the useful arts.

Section I.—The Waters.

3. Water, one of the most abundant and powerful agents of nature, was one of the very few elements of ancient philosophy:—indeed, the names of Becher and Stahl remind us that, even past the middle of the last century, water was one among the bodies enumerated as simple elements; Becher having advocated three such elementary bodies, viz., *air*, *water*, and *earth;* and Stahl having appended to them a fourth, viz., *phlogiston*, or the principle of *fire*. Modern science, however, has proved the compound nature of water; and has demon-

* From ὑδωρ, *water*, and μετρεω, *to measure.*

strated, by beautiful and convincing experiments, that it is composed of two volumes of hydrogen and one of oxygen gas. Hydrogen is sixteen times lighter than its own bulk of oxygen; in fact, it is the lightest body in nature which the most delicately-constructed balance has ever weighed.

4. All those bodies are termed fluid, which are supposed to result from a collection of material particles, whose size is infinitely small, and which move freely on each other in every direction, without the retarding agency of friction; in this sense, water, oil, mercury, steam, vapour, and air, are all fluids. Another distinctive property of fluids is, that when confined by pressure, they also exert a pressure which is equal in all directions. These properties are general, and apply to all fluids; but most important distinctions are observable in the two sub-sections into which fluids may be divided. If we have a cubic foot of air, and by some mechanism be enabled to enlarge the capacity of the containing vessel to two cubic feet, without letting in fresh air, the air already in the vessel will instantly fill the whole of the enlarged capacity; but, if the cubical vessel contain water in the first instance, the enlargement of the vessel will not cause an enlargement in the bulk of the water; the latter will remain the same in bulk as before. This distinction is conveniently denoted by the terms *elastic* and *non-elastic*, the former being applied to those fluids which would fill a containing vessel, however much its capacity may be increased; and the latter to those, which suffer no change of bulk from that circumstance. These non-elastic fluids, such as water, oil, spirits, mercury, &c., are in common language known as *liquids*, and the elastic fluids as *airs:* the term *non-elastic*, however, requires a reservation, of which we shall treat presently (11). Elastic fluids are further divided into two species, in order to indicate the peculiarities which distinguish *vapours* from airs: the term *vapour* being applied to those airs, whose liquid origin is familiar to us at ordinary temperatures. Thus, if water be reduced in temperature, it becomes solid; if its temperature be elevated, it is vaporized, or converted into a vapour which is visible; if it be heated still more, out of contact from the cool air, it becomes *steam*, which is invisible, and that steam possesses the fluid property of *expansibility;* but upon a reduction of temperature, it regains the liquid form. Now, as a similar phenomenon never occurs with common air, it is convenient to adopt the distinctive term of *vapour* for the aëriform state of water.

5. Another distinction between the different kinds of fluids has been often instituted. Those which have the property of

adhering* to other bodies have been called liquids, such as water, oil, &c., while those which do not possess this property have been considered as fluids, such as air, melted metals, mercury, &c. Now, that this distinction will not hold, the arts furnish us with a striking proof. When the surface of a metal is covered with gold, it is said to be *watered;* while a similar metal, covered with silver, is said to be *plated.* Now the two dissimilar metals adhere by a force which is called *affinity;* and, although mercury will not stick to the hand, (like water,) yet there are many metals to which it will adhere. Gold has an affinity for many metallic bodies; or, to speak technically, it *waters* these bodies; mercury also waters gold, silver, tin, lead, &c.; and the force of attraction between mercury and other metals has been calculated in the following manner. When a smooth plate of any substance is brought in contact with the surface of a liquid, a greater force is necessary to raise it than when it is not so in contact. This excess of force is the force of adhesion, and continues the same in each body, provided the surface remains the same. Different metallic disks of the same size adhere to mercury with forces represented by the following figures:—

Gold	23·63	Platinum	14·98
Silver	22·74	Zinc	10·81
Tin	22·15	Copper	7·52
Lead	21·04	Iron	6·10
Bismuth	19·71		

But all the distinctions between fluids and liquids are uncertain, and cannot be insisted on, since many of the gases which were once called *permanently elastic*, i. e., incapable of being reduced to a liquid or solid form, have, through the united agency of pressure and low temperatures, been reduced to the liquid state; and analogy would lead us to suppose that all the gases, and even atmospheric air, are capable of being reduced to the liquid, or even to the solid form, if we could only command sufficient pressure, and procure a temperature sufficiently low. The necessity for a low temperature will be seen, when we remind the reader that heat produces expansion in all bodies, and that upon heat alone does the very existence of several forms of matter depend.

6. In our paper on the Barometer we pointed out the

* The term *cohesion* is frequently introduced in opposition to *adhesion:* the former implies that force by which the particles of a substance are held together; the latter applies to that force by which they cling to other bodies.

chief properties of the atmospheric air, under the terms impenetrability, inertia, mobility, and weight;—we need not now consider the same properties with reference to water, as their application is nearly the same: we proceed, therefore, to notice other phenomena which belong more exclusively to liquids.

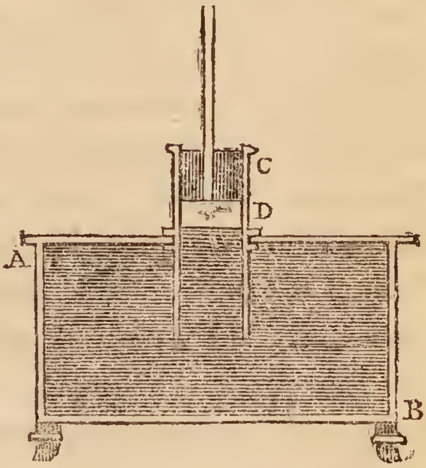
7. The first and most striking property of liquids is the tendency they all have to adjust themselves to a horizontal level; this is due to their mobility, or the facility with which they move, and the tendency of all their particles to fall as low as possible. Its operation may be seen on a grand scale in nature,—in the motion of mighty rivers, as well as in that of the most insignificant brook: in the fall of the stupendous cataract, or of the minutest waterfall:—all are hastening on, guided and directed by the all-pervading force of gravity, in search of the lowest level;—forming in their course, the mountain-torrent, the expansive lake, the river, the brook;—and producing that exuberant wealth to the vegetable-world, and healthful freshness to the animal-world, which cannot be sufficiently appreciated, until we form a contrast of all this with the arid deserts of Arabia, where a cup of cold water is above all price, and which is often not to be purchased with gold.

8. In consequence of the perfect mobility of water, the liquid level is the only perfect level with which we are acquainted in nature or in art. A still lake, unruffled by the slightest breath of air, is one of the finest examples of a perfect level that we possess. Being formed by the attraction of gravitation, it follows, however, that this level is not, (as we are accustomed in common language to call it,) *horizontal*, but partakes of the earth's curvature. Every portion of the lake's surface is, therefore, equi-distant from the centre of the earth (excepting that slight deviation due to the spheroidal figure of the earth); but so small a proportion does a sheet of still water bear to the diameter of the earth, that the curvature of the water is not at all perceived; and for all ordinary practical purposes fluid surfaces of small extent may be considered as plane. If we suppose a line tightly drawn across a perfectly still lake of the diameter of two miles, and fastened at two opposite points of the circumference;—if the ends of the line just touch the surface of the water, the line will dip under the water four inches only, in the centre;—that is, the centre of the lake will be four inches higher than the edges, considered with reference to a straight line; a degree of elevation which, in practice, is almost inappreciable. Hence we learn that a perfect level on the earth's

surface is never a right line or a plane surface, but a portion of a curve of nearly 4000 miles radius.

9. A second important property of liquids, is that of transmitting pressure in all directions. From our definition of a liquid (4), it follows that any disturbing force causes it to yield, whether this force be the gentlest breeze, or the mighty power which produces the spring-tides. But, in these cases, a liquid is set in motion by a force, because the liquid is free to move; and if subjected to force, can only be at rest when forced in all directions. If a liquid, such as water, be confined in a close vessel such as A B, fig. 1, entirely filled, having an aperture at D, in which is inserted a cylinder C, descending into the liquid,—if such a vessel as this be filled with air instead of water, the piston contained within the cylinder might be forced down, and the resistance of the air to compression would not be very great; but water would so effectually resist compression, that the vessel A B would burst out before the water yielded to the force exerted on the piston. This is, in fact, what would ensue, supposing so small a force as one pound were exerted on the piston, the contents of whose base we will suppose to equal one square inch.

Fig. 1.



10. Now, the force exerted on the inner surfaces of the vessel is easily calculated, (supposing the surfaces to be plane). We have only to multiply the length of each surface (in inches) by its breadth, which will give its area; then by adding the area of all the surfaces, we shall get the whole interior or exterior surface of the vessel. Thus, suppose the total area of the inner surfaces of the vessel amounted to 8,000 square inches, each square inch would have to bear the pressure of one pound exerted by the piston; the total force, therefore, tending to burst the vessel would amount to the enormous sum of 7999 pounds, a force which few vessels would be able successfully to resist.

11. Now, the reason of all this is to be found in two properties of liquids, which are here simultaneously in operation. The first is the perfect *mobility* of water, by which it so readily yields to any impulse when it is not confined; and the second is that remarkable property which may be called its *incompressibility*, since it is sufficiently correct (for all *practical* purposes)

to consider liquids to be incapable of occupying a smaller space by pressure than they already occupy in their free state. Still, however, the accurate rigour of modern science will not allow us thus to pass by a property which seems common to all matter; and although the compressibility of liquids is small, yet the very circumstance of their being compressible at all, is sufficient grounds for us to notice this property. By a series of fine experiments, M. Œrsted has discovered that a pressure equal to a column of water 32 feet high produces in pure water a diminution of 0·000045. Canton had previously found that, under the same pressure, the following liquids underwent the following diminutions:—

Sea-water . . .	0·000040
Rain-water . .	0·000046
Olive-oil . . .	0·000048
Spirit of wine . .	0·000066
Mercury . . .	0·000003

These diminutions are nearly in the inverse ratio of the densities of the liquids. Mr. Perkins, in a series of experiments with a pressure 1120 times greater than that employed by M. Œrsted, is said to have produced a diminution of 0·06. We shall return to this subject when we come to speak of the density of liquids.

12. Since a liquid, then, confined in a close vessel, cannot be much compressed by any ordinary force;—and as all the particles of a liquid are so connected as to press equally in all directions;—as each particle is pressed by the adjacent particles, whether they be above, below, or on any side;—and as all the particles in their turn press upon all the sides of the vessel which contains them with a force of their own, depending upon the height of the fluid multiplied by the extent of surface upon which it rests; it follows, that any force communicated to the liquid is equally dispersed through and transmitted by the watery particles; and hence it is, that the surface of the containing vessel receives so enormous a pressure from a force apparently insignificant.

13. But although the most gigantic mechanic power which man can command, fails to compress water to any considerable extent, yet Nature reduces its bulk with unerring precision, by means, certain though silent in their action, and, like all her operations, beautifully simple. The mere abstraction of heat is sufficient to effect this; and we find, accordingly, that all bodies contract in bulk by cold, (cold being, in fact, nothing more than diminished heat, and not a principle in itself,) and expand by

the application of heat*. Now, it is very important to our present purpose to ascertain the chief points which regulate the change of bulk in liquids, by change of temperature; and water being the most important, as it is the most abundant, of the liquids, we shall chiefly confine our observations to it; first, premising that the general laws which regulate the contraction of water, apply, for the most part, (but not altogether,) to other liquids.

14. The reader will have a clear view of the nature of expansion, by considering that "matter of every kind is nothing more than an assemblage of material particles, held *in equilibrio* by the force of cohesion, which tends to unite them, and by a repulsive force, (which is probably caloric, or the principle of heat,) which tends to separate them."—*(Biot.)* In proportion to the presence of this principle of heat, we get the various states of matter, solids, liquids, and airs; in short, one may be resolved into the other by the application or abstraction of heat. Of the three states of matter, airs alone expand equally for equal increments of heat, the rate being $\frac{1}{480}$th part of their whole bulk at 32° for every degree of Fahrenheit's thermometer; but no such law regulates the expansion of solids and liquids, since it appears that every solid and liquid has an expansibility peculiarly its own. It is important, therefore, in treating of liquids, to ascertain the amount of expansion of each, under a given increase of temperature; and this has been done with much precision by various philosophers. The following table shows the expansion of a few liquids, from 32° to 212°, the bulk at 32° being considered as unity:—

			Equal to an increase in the whole bulk of
Alcohol	0·11000	=	$\frac{1}{9}$
Fixed oils	0·08000	=	$\frac{1}{12}$
Sulphuric ether	0·07000	=	$\frac{1}{14}$
Oil of turpentine	0·07000	=	$\frac{1}{14}$
Brine, or water saturated with salt	0·05000	=	$\frac{1}{20}$
Water	0·04444	=	$\frac{1}{22\cdot5}$
Mercury	0·018018	=	$\frac{1}{55\cdot5}$

Water, it will be seen, by gaining an accession of heat equal to 180°, gains an increase in bulk equal to rather more than one part in twenty-two; or, to speak more familiarly, 22 pints of water at 32°, become 23 pints at 212°.

* Water is not so susceptible of compression in high temperatures as in such as are lower. The very act of compression, too, occasions a rise in temperature. M. Œrsted found that a difference of one degree of Centigrade caused, at high temperatures, the volume of the water to vary more than the pressure of three, four, or even five atmospheres.

15. From what has been said, it would be naturally inferred that, as by the addition of heat, liquids expand* in bulk, so by a diminution of heat their relative and respective bulks would be diminished. But it is a most remarkable fact,—important not only in science, but also in the arts,—that water, and a few other liquids†, contract by cold only within a certain limit, beyond which, if cold be continually applied, all contraction ceases; nay, on the contrary, expansion re-commences just as if heat were applied.

16. This very curious and instructive phenomenon was first noticed, in water, by the Florentine academicians, about the year 1670. They filled a glass ball, which had a long and narrow neck, with water, and plunged it into a mixture of salt and snow, which produced the most intense cold known at that time. The water suddenly started up in the neck, in consequence, (as it would appear,) of the contraction of the glass vessel by cold; but the water also soon contracted, as it parted with heat, and its contraction continued down to a certain point, when it began to retrace its steps:—it expanded, and ascended slowly in the tube, until a portion of the water in the bulb became solid ice, and then the water in the stem shot up suddenly with considerable velocity. Modern science has determined, with its accustomed accuracy, the temperature when water ceases to contract by cold, and when expansion begins, from the same cause, to be 39·38° Fahr.; and this is called the state of greatest condensation of water, which, (as we state in our paper on the "Vernier," 9,) has been adopted by the French as the basis of their system of weights. It will be remembered, then, that at about 40°, water is in its state of greatest condensation;—that is, it is reduced to the smallest possible dimensions of which it is susceptible by cold alone, and that its particles are as closely connected together as possible. The physical reason why expansion takes place after this, seems to be a

* Enlargement in bulk by the application of heat is sometimes termed *dilatation*, and sometimes *expansion*. The former term, however, rather implies an enlargement laterally, in one direction only, *breadth-wise*, as we should say, and therefore is not so appropriate as the term expansion.

† Among other bodies which experience an increase of volume in passing from the liquid to the solid state, we may mention iron, bismuth, bronze, antimony, &c. Antimony is put into the lead with which printers' type is formed, because the expansion of the melted metal, on solidifying, fills up the mould, and gives that sharp, full appearance to the letters, which could not be ensured by lead alone, which contracts on solidifying instead of expanding.

re-arrangement of particles, by which the crystalline form of the solid which is about to be produced occupies more space than the particles in the liquid form.

17. The point of greatest condensation of water by cold, and its subsequent expansion from the same cause, may be demonstrated by an admirable experiment, due to Dr. Hope. He filled a deep, glass, cylindrical jar with water at the temperature of 50°, and set it in a very cold room. He then placed two thermometers in the water; the bulb of one dipping just beneath the surface, while that of the other was sunk to the bottom of the jar. He then watched their indications, as the cooling proceeded. The water, cooling at the surface, became denser than that immediately below it, and therefore sank to the bottom; and so on successively. So that the upper thermometer indicated a higher temperature than the lower one, until the temperature fell to 40°, when the two instruments indicated the same temperature for some time. As the cooling proceeded, the upper thermometer noted the lower temperature of the two; that is to say, when the temperature on the lower strata attained 39·38°, expansion ensued, and a consequent decrease of density; so that the colder water occupied a superior position to that which was less chilled. The following table represents three of the conditions, in which the water was placed in this experiment.

42°	Before maximum density was attained.	$39\frac{1}{2}$°	At point of maximum density.	38°	Below temperature of maximum density.
40°		$39\frac{1}{2}$°		40°	

18. The apparent exceptions to a natural law, however perplexing they may, at first view, appear to the student in science, become, when viewed by the instructed confidant of Nature, so many beautiful extensions of the same law; or rather, when the operation of one law ceases, the governing power is taken up by another, and carried on as if it were part and parcel of the original law. Thus, steam is subject to the general and equable law of expansibility, which regulates all airs; but when, by a reduction of temperature, steam is condensed into water, the laws of liquid expansion apply, and when it becomes solid ice, a third general law regulates its varying bulk. Now, supposing that water regularly contracted from its liquid to its solid state, it is quite clear that a certain bulk of ice would occupy less space than the bulk of water which formed it; its weight would be, in short, bulk for bulk, greater than that of water, and it would consequently sink; and our streams in winter, instead of

the superficial crust of ice which covers them, and which is easily thawed, would become one solid mass of ice,—destroying all that life with which the waters teem,—and would take a whole summer to become again liquid, since water is so imperfect a conductor of heat.

19. We have spoken of the point of greatest condensation of water as a fixed point;—as a natural standard which is presumed to be invariable. Now the freezing-point of water, all over the world, is 32° Fahrenheit; but, as our readers know, its boiling-point is variable, depending upon atmospheric pressure. It follows, then, that pure water at a fixed temperature occupies the same bulk all over the globe:—that a pint of pure water at 60° is absolutely a pint, and neither more nor less at any time or place where it may happen to be.

20. When we speak of pure water, we do not mean that of the "limpid brook," "the majestic river," or "the deep, deep sea;" for, however pure the waters of these sources may be, in poetry, they are absolutely impure for scientific purposes. The waters of the brook, and of the river, flowing over mineral beds, dissolve and hold in solution various substances, depending upon the nature of the bed. In some waters are found chalk, magnesia, oxide of iron, and other bodies, which render its weight variable; and sea-water contains much salt and other matters, all which prevent the one or the other sort of water from being taken as a standard of universal reference. Now, pure water may be obtained by distillation; that is, by raising the temperature of the water to the boiling-point;—when its vapour will pass off, and leave all the other matters, which are considered as impurities, behind. If the vapour be received into a cool vessel, it will be condensed, and will yield water absolutely pure;—that is, it will furnish, by analysis, oxygen and hydrogen, and nothing more.

21. We have purposely delayed until now, the consideration of another property of water, viz., its *density;* because this is so intimately connected with that which is immediately to follow.

In consequence of the attraction of cohesion operating less perfectly in liquids than in solids, gravity acts with full force upon the former,—producing a horizontal level, the result of equal attractions towards the centre of the earth; but in solids, if a single point, the centre of gravity, be supported, the whole mass will be in equilibrium. All the particles of a liquid, then, are tending to the lowest point; and consequently the base of a liquid column is, in addition to its own gravity, subject to that

of the whole liquid mass above it: hence, if a hole be opened in the bottom of a vessel full of water, the liquid will rush out with a force proportioned to its distance from the top of the vessel. Thus, if a cylindrical vessel, six feet in height, had an orifice in the bottom of such a size as to suffer all the water to flow out in half an hour, and if this vessel were filled with water, the water would begin to flow out with a rapidity of 11½ inches in the first 2½ minutes, but after it had been flowing 27½ minutes out of the 30, 71½ inches out of the 72 would have flowed out, leaving only half an inch of water to flow in 2½ minutes; in other words, the rapidity of the flow is twenty-three times as great when the vessel is filled to the top, as when it is filled to half an inch*. This results from the law, that the quantity which flows out in a given time is not simply as the height, but as the square of the height. The same law regulates the flow from any other aperture in the side of the vessel. If an open tube be inserted vertically in the vessel, the liquid will immediately ascend the tube, until this level corresponds with that in the larger vessel; this shows the downward, lateral, and upward pressure of liquids:—but suppose the liquid

* Should the reader experience any difficulty in accounting for the great disparity between the quantity of water which escapes during the first and the last 2½ minutes of the half-hour, he is reminded that the velocity of the flow decreases in the same ratio as the velocity of a falling body increases:—thus, if a stone fall from a height towards the earth, and during the first unit of time (which may be one second, one minute, or two and a half minutes, or any number agreed on), through a space represented by one, it will fall through three times that space during the 2nd second; through five times that space during the 3rd second, and so on; the spaces fallen through being in proportion to the squares of the times: thus $1 + 3 = 4$ which is the square of two seconds; $1 + 3 + 5 = 9$ or 3^2; $1 + 3 + 5 + 7 = 16$ or 4^2, and so on. The following table will render the statement made in the text still more simple—

23	half-inches flow during the	first	2½ minutes.
21	. . . . .	second	2½ minutes.
19	. . . . .	third	2½ minutes.
17	. . . . .	fourth	2½ minutes.
15	. . . . .	fifth	2½ minutes.
13	. . . . .	sixth	2½ minutes.
11	. . . . .	seventh	2½ minutes.
9	. . . . .	eighth	2½ minutes.
7	. . . . .	ninth	2½ minutes.
5	. . . . .	tenth	2½ minutes.
3	. . . . .	eleventh	2½ minutes.
1	half-inch flows during the	twelfth	2½ minutes.
144	half-inches, or 6 feet.		30 minutes.

column be continued downwards to an indefinite extent, it follows that the lowest stratum of water, having to bear the weight of that above it, will be compressed, (for we have seen that water is compressible), (11); the compression of course depending upon its own superincumbent weight. Professor Leslie has observed, that if air be compressed into the fiftieth part of its column, its elasticity becomes augmented fifty times; that if it continues to contract at that rate, it will from its own incumbent weight, acquire, at the depth of thirty-four miles, the density of water; that water itself, at the depth of ninety-three miles, would have its density doubled, and would even acquire the density of mercury at the depth of three hundred and sixty-two miles. At the centre of the earth, Dr. Young says steel would be compressed into a fourth, and stone into one eighth of their bulks.

22. Let not the reader smile at these statements, and feel disposed to place them in the romance of science; since the names of the profound and admirable philosophers, under whose sanction they are here given, are quite sufficient to repress the vulgar clamour of ignorant incredulity, when it is known what are the data upon which these conclusions are founded. Great names should not certainly command implicit belief, but they should command respect; for, although philosophers are not yet acquainted with the laws of compression of solid bodies beyond a certain limit, yet, that the above calculations are not overstated, appears certain, if we may rely upon some experiments of Mr. Perkins, on the compressibility of water. He constructed an apparatus which consisted chiefly of a stout cylinder of brass, containing water, and a rod moving in the top through an air-tight and water-tight hole; the top of this rod was furnished with a spring ring, which remained fixed at any point at which it was placed, and, therefore, served as an index of compressibility. Having plunged his apparatus into the sea, five hundred fathoms deep, the ring was found to stand eight inches high on the rod. From this he inferred that the rod had, at the greatest pressure, been forced eight inches into the cylinder; and as the spring could not enter the latter with the piston, it was consequently thrust up the handle, where it remained fixed. Mr. Perkins calculated that the water had been compressed $\frac{1}{27}$th part of its bulk.

23. By density, then, we mean the quantity of matter enclosed within a certain space; and the more matter this space contains, the denser is the body which is enclosed by such space, and *vice versâ*. Two bodies, then, which enclose the same

quantity of matter in the same space, are equally dense,—the temperature of both being the same. Thus, a cubic inch of gold will weigh precisely the same as another cubic inch of gold, of the same purity, because both are of the same density; but a cubic inch of standard gold, (that is, gold containing $\frac{1}{12}$th silver,) would differ in density from a cubic inch of pure gold. Density and weight are very distinct properties, for it is clear that a mass of cork may weigh exactly the same as a mass of lead, but the masses would not correspond in bulk; and this is quite sufficient to lead to the conclusion that cork is not so dense a body as lead, although, in this case, the weights of the two bodies may be the same.

24. We say familiarly, that cork floats on water, and that lead sinks; but from what has been shown of density, it by no means follows that a certain density of water may not be found in which lead would float; the only condition necessary is, that the lead and the water be of the same density; and if it were within the bounds of probability that the sea be in some places so deep, that, as the sounder declares, there is "*no bottom*," lead at a certain depth would float with as much facility in water as it does in mercury. Indeed, the depth at which lead floats in water is a matter of easy calculation; and it is by means of a given weight of this metal that an object is sunk to a given depth. Thus, Mr. Perkins employed fifty-four pounds of lead, in order to insure a depth of five hundred fathoms for his apparatus for ascertaining the compressibility of water, and this depth gave a pressure equal to one hundred atmospheres.

25. We have now arrived at the last part of the present section, wherein we propose to consider what apparent change a solid undergoes by immersion in a liquid.

It is a consequence of the impenetrability of a liquid, that every solid, when plunged into it, displaces a quantity exactly equal to its own bulk. It is also a consequence of the pressure of the particles of a liquid upon each other, that a lighter body floats upon its surface; that a body of equal weight remains at rest at the place where, having been immersed, it is allowed to remain; and that a heavier body sinks in it; the descent being, however, retarded by the resistance of the liquid operating against the gravitating force of the solid. By measuring the exact quantity of liquid displaced by a solid, we ascertain, with great precision, the bulk of the latter. It matters not whether the solid be very heavy or very light:—a certain bulk will displace a certain quantity of liquid, and no more.

26. If a body be weighed in air, and afterwards weighed

in a liquid, it will appear in the latter process to have lost a part of its weight, and this loss, it will be found, is exactly equal to the weight of the quantity of the liquid displaced by the solid. Therefore, by dividing the weight of the body in air, by the difference between that weight and its weight in the liquid, we ascertain how many times the weight of a certain bulk of liquid displaced, is contained in the weight of the same bulk of the substance we are weighing: or, in other words, we ascertain its *specific gravity*.

The reason of this process will be, perhaps, better seen by putting it into the form of a proportion, thus:—

As the loss of weight, when weighed in water
: Is to the weight of the body in air,
: : So is the weight of a given bulk of water
: To the weight of an equal bulk of the solid;
(or, so is 1, to the specific gravity of the solid).

27. Now it is of the first consequence that the term *specific gravity* should be understood in the same manner all over the world; so that philosophers in one country may repeat and verify the experiments of those in another. It is necessary, therefore, to adopt some universal standard of comparison; and for this purpose pure water, at a certain temperature, is the most eligible. The best temperature would probably be the point of greatest condensation: but as this temperature would in summer, and in warm countries particularly, be inconvenient to procure, the temperature of 60° is generally adopted. A fixed temperature is not, however, absolutely necessary:—the specific gravity of any substance may be taken, at whatever temperature water may be found to be; since tables are constructed expressing the change of weight which a given bulk of water sustains with every change of temperature; so that a simple arithmetical process is sufficient to reduce the specific gravity of any substance to what it would have been at any other proposed temperature.

28. The adoption of water, as a standard of comparison, took its rise from a circumstance as little likely to lead to scientific results as the fall of the apple, which our immortal Newton is said to have witnessed in his orchard. But let us not suppose that so trivial a circumstance as this, suggested the sublime theory of gravitation to the mind of our noble countryman: for it is not by sudden and "happy" thoughts, as they are termed, that we gain admission into the secret workings of the universe. Nature selects her favourites, not with the blind

partiality of Fortune, from the dissolute and the idle, as well as from those whose mental stores are great and well applied; but her choice is from those alone who have undergone the rigorous and wholesome mental discipline which constitutes the very language in which she communicates her precious knowledge. What the world calls an accidental discovery in science, is a sad misapplication of terms. Any man may accidentally discover a large sum of hidden coin; but no man ever made the accidental discovery of a hidden principle of nature, which had defied all the powers of the good and the wise of past ages. His mind must be prepared, by cultivation, for the reception of the hidden truth, in the same way as the good ground spoken of in the parable which, "received seed and brought forth, some an hundred-fold, some sixty-fold, some thirty-fold;"—but how often is it that the seeds fall into "stony places," where, because "they take no root, they wither away?" But to return:—

Hiero, king of Syracuse, had given a workman a quantity of gold, with which he was to construct a crown. When the crown was made and sent to the king, a suspicion arose in the royal mind that the gold had been adulterated by the alloy of a baser metal, and he applied to Archimedes, a celebrated philosopher, (who lived from 287 to 212 B.C.) for his assistance in detecting the imposture. As, at that time, there were no known means of testing the purity of metal, this philosopher, after many unsuccessful attempts, was about to abandon the object altogether, in despair of being able to accomplish it, when the following trivial circumstance (to which we have just alluded) suggested to his discerning and *prepared* mind a train of thought, which ended in the accomplishment of the proposed object. Stepping into his bath one day, as was his custom,—his mind, doubtless, fixed on the object of his research,—he chanced to observe that the water rose in proportion as he plunged his body into the liquid, and that the proportion bore a relation to the bulk of his body. He probably perceived that any other body of the same bulk would have raised the water equally; but that another body of the same weight, but less bulky, would not have produced so great an effect. At this moment he must have experienced that intense pleasure which can only be appreciated by those who have felt the truth of a principle,—sought for by long and patient labour,—rush suddenly into the mind. The joyous effect upon Archimedes is said to have been such as to cause him to leap from the bath, and to run into the street, exclaiming *Εὕρηκα*! *Εὕρηκα*! "I have found it out! I have found it out!" When his emotion had sobered down, he

proceeded to investigate the subject calmly. He procured two masses of metal, each of equal weight with the crown,—one of gold and the other of silver; and having filled a vessel very accurately with water, he plunged into it the silver, and marked the exact quantity of water that overflowed. He then treated the gold in the same manner, and observed that a less quantity of water overflowed than before. He then plunged the crown into the same vessel, full of water, and observed that it displaced more of the fluid than the gold had done, and less than the silver; by which he inferred that the crown was neither pure gold nor pure silver, but a mixture of both.

29. The problem which Archimedes had to solve would be to us, of course, easy, when the specific gravity of gold, of silver, and of the crown, is known. If the specific gravity of gold be taken at 19 (that is, any mass of gold would be 19 times heavier than the same mass of water), silver 10, and king Hiero's crown 15; then the difference of the specific gravities are 9, 5, and 4; the products of each specific gravity, by the difference of the other two, are 135, 95, and 40: therefore, as 135 : 15 : : 95 : 10·555; and again, as 135 : 15 : : 40 : 4·444, whence the proportion of the gold to the silver in the crown, is as 10·556 to 4·444.

30. We have given the rule for ascertaining the specific gravity of a substance heavier than water. If, however, a substance be, bulk for bulk, lighter than water, some heavier body must be attached to it, whose specific gravity is previously known. The bodies, thus attached, are weighed together in air and in water, and the difference found. From this difference is subtracted the difference between the weight of the heavier body in air and in water; and by these means the weight lost by the lighter body in water is ascertained,—by which its weight in air must be divided, in order to find its specific gravity: or expressed proportionally, thus:—ascertain what loss of weight the heavy body undergoes, on immersion in water, and then what loss the compound body undergoes:—then

As the difference between the losses
: Is to the weight of the light body in air,
: : So is 1
: To the specific gravity of the light body.

If the body to be weighed, although heavier than water, be in the form of filings or grains, the following mode must be adopted. Put the filings into a small bucket, or cup, having previously weighed the empty bucket in air; then the difference between

the weight of the full bucket and the empty bucket is the weight of the filings in air. Perform exactly the same process in water, and we get the weight of the filings in water: then—

As the difference of those weights
: Is to the weight of the filings in air,
: : So is 1
: To the specific gravity of the filings.

31. The specific gravity of a fluid is easily found by employing a bottle which is counterpoised in the scale, and which would contain exactly 1000 grains of distilled water at 60°: it evidently follows that, if the bottle be filled with a fluid denser or lighter than water, the equipoise will be in either case disturbed; and the number of grains added to the lighter scale will show the specific gravity of the fluid in question.

32. We will now give examples of the mode of taking the specific gravities of three distinct substances:—first, a heavy solid; secondly, a light solid; and thirdly, a liquid. i. In order to ascertain the specific gravity of a piece of stone, which in air weighs 600 grains, and in water only 400, we find that a quantity of water, equal in bulk to the stone, would weigh 200 grains; now, the weight of the stone in air is 600, which, divided by the weight of the water, corresponding to the bulk of the stone, gives 3; the stone is therefore three times heavier than the water. If we call the specific gravity of water 1, that of the stone will be 3; if we call the specific gravity of water 1000, that of the stone will be 3000;—for it evidently matters not whether the unit of comparison be 1 or 1000; the result is the same; since the object of obtaining the specific gravity of a body is not to ascertain its actual weight, but its density, or the number of times that the weight of an equal bulk of a known standard is contained in the weight of such body. In practice, however, it is found convenient to employ 1000 as the numerical denomination of the standard: as it happens rather remarkable that a cubic foot of water weighs, within a small fraction, 1000 ounces. When, therefore, we see that the specific gravity of any body, a metal, for instance, is put at 7·525, we know that a cubic foot of it weighs 7,525 ounces, or 470 pounds 5 ounces avoirdupois; which gives 4·355 ounces as the weight of a cubic inch of the metal.

33.—ii. To find the specific gravity of a piece of light wood, which, in air, weighs 5 ounces, we may attach to it a smooth stone, which, in air, weighs 12 ounces, and in water 6, making a difference of 6 ounces. The stone and the wood,

when attached, weigh 17 ounces in air, and only one ounce in water, making a difference of 16 ounces. From this difference we deduct the difference found before between the weight of the heavier body in air and in water; and thus we obtain the difference 10, between the weight of the lighter body in air and in water. By this difference 10, we divide the weight of the lightest body in air, 5, and thus find the specific gravity to be $\frac{1}{2}$, if water be accounted 1, or 500, if the specific gravity of water be set down at 1000.

34.—iii. The bottle (31) being filled with a liquid, say alcohol, and placed in one of the scale-pans, and a weight which exactly counterpoises the bottle when empty, being placed in the other, together with 1000 grains weight, equal to 1000 grains of water at 60°, it is evident that these two weights would counterpoise the bottle, if filled with water at 60°, but if filled with a fluid lighter than water, as alcohol, the two weights would be too heavy for the bottle and its contents; we, therefore, add weights to the pan containing the bottle, until that pan equipoises the other. Suppose the weights added amounted to 198 grains: this deducted from 1000 grains would give 0·802, the specific gravity of the alcohol. If the liquid were heavier than water, it would be necessary to add weights to the 1000 grains; the bottle being filled with strong sulphuric acid, for example, we should have to add 700 or 800 grains to the 1000, and this would indicate a specific gravity of 1·700 or 1·800, as the case might be.

35. We will conclude this section with a notice of the specific gravities of a few well-known substances.

WOODS.		LIQUIDS.	
Cork	0·240	Sulphuric ether	0·715
Poplar	0·383	Absolute alcohol	0·792
Apple	0·793	Spirit of wine	0·837
Beech	0·852	Distilled water	1·000
Oak	0·925	Sea-water	1·026
Mahogany	1·063	Milk	1·030
Pomegranate	1·354	Mercury	13·586

METALS.	
Potassium	0·865
Iron	7·207
Silver	10·474
Lead	11·352
Gold	19·362
Platinum	22·069

36. The specific gravities of gases are compared to that of pure and dry atmospheric air, which is stated as 1 or 1·000.

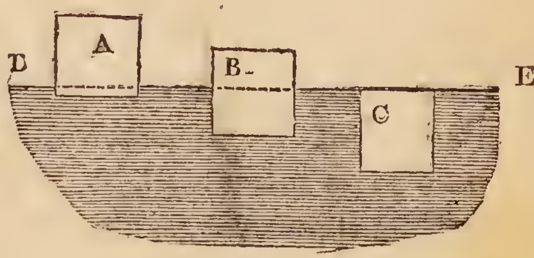
Thus, the density of chlorine is 2·5 or 2500;—that is to say, it is two and a half times heavier than air.

SECTION II. ON HYDROMETRICAL INSTRUMENTS.

37. HAVING now treated of the principal properties of liquids which influence their density, we will proceed to describe various contrivances which have been devised for measuring variations in that density. The details just given, relate for the most part, to the density of solids; but it is important to bear in mind, that the density, or specific gravity, of liquids is, in almost all cases, however different in minor details, ascertained by the depth to which a solid will sink in them.

38. Before proceeding to a description of hydrometrical instruments, we will at once show, by two figures, the difference between ascertaining the specific gravity of liquids, and that of solids. First let us speak of solids. We have three cubical pieces of different substances, but of the same size,—say one inch cube. We immerse them in a given liquid,—say water,—and we see that A (fig. 2) sinks to one quarter of an inch below the surface D E, B to half an inch, and C sinks wholly below the surface, and floats about indifferently in every part. We then know that A has displaced one quarter of a cubic inch of water, and as that equals the whole weight of the body, we say that the density, or specific gravity of water, is four times that of the solid, or, if the water be 1000, solid is 250. B displaces half a cubic inch of water, and is, therefore, to water as two to one in bulk, or as half to one in density, thus giving 500 as its specific gravity. As C sinks wholly below the surface, but is indifferent to position in other respects, its specific gravity is equal to that of water. If, however, C do not remain suspended, but fall to the bottom, the force of that tendency, or its weight in water, must be added to the specific gravity of the water, to get the real specific gravity of C.

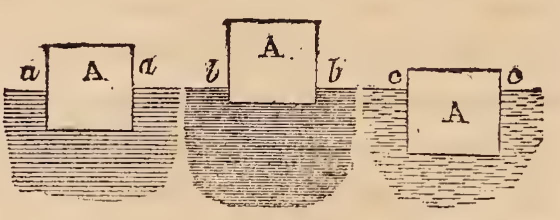
Fig. 2.



39. But now, to measure the specific gravity of *liquids*, one solid and two or more liquids must be employed; in the former case, one liquid and two or more solids were necessary. If this difference be borne in mind, it will show at once the difference of the principle employed.

40. We have three liquids, (fig. 3), *a a*, *b b*, *c c*, the comparative densities of which we wish to determine; we take a solid of a definite size and weight, A, which, when placed on water, sinks to half its depth, as in *a a*. This (water being the most convenient standard) is assumed as a standard; it matters not to what depth it sinks, but we have assumed half its height, for convenience of illustration: the density, then, of that liquid is double that of the solid. The solid is then placed on the second fluid, *b b*, but it sinks only one quarter of its bulk, thus showing that the density of that fluid is four times that of the solid. In the third liquid, *c c*, three quarters of the solid sinks, which indicates that the density of the liquid is to that of the solid as four to three. If, therefore, the density or specific gravity of *a a* be taken as a standard, and called 1, that of *b b* will be 2, and that of *c c*, 0·666.

Fig. 3.



41. The reader will at once perceive the difference between these two modes of experiment. To ascertain the specific gravity of solids, they are all weighed in one given liquid, as before detailed; but to measure the specific gravity of liquids, one given solid is immersed in them all; and the different modes of estimating that immersion we will now proceed to describe.

42. The hydrometer is said to have been invented towards the end of the fourth century, by Hypatia, a lady celebrated for her acquirements in literature and science, a distinction which, unhappily for herself, excited the envy of her contemporaries, and to this she fell a victim during an insurrection at Alexandria. She contrived this instrument as a means of ascertaining the purity of water, upon the principle of floating bodies, discovered by her immortal and equally unfortunate predecessor, Archimedes.

43. It has been already explained, that a body, floating in water, displaces a portion of the fluid precisely equal to its own bulk;—that, as the density of water increases with the depth, a solid would continue to sink until its own density and that of the water corresponded; or, which is the same thing, a solid floating in different liquids, of different specific gravities, would settle at various depths in all of them: and that, in proportion as the density of a liquid is small, the corresponding depth to which the solid would sink would be increased. It evidently follows, too, that another solid, capable of floating on water,

would, in order to float on a lighter fluid, displace more of the latter than of the former, and a larger portion of the solid would be submerged.

44. It is a common remark, that it is easier to swim in salt than in fresh water; and the remark is just, because the density of the one is greater than that of the other. A common test of the quantity of salt necessary to add to water, in making brine for pickling meat, is to continue to add salt until an egg will swim in it*. This seems to have suggested the idea of the hydrometer, which consists of a hollow brass ball, in the form of an egg, with a stem proceeding from the larger end, and another from the smaller, which latter bears a weight, to preserve the stability of the instrument in liquids. This, then, is the common form of the hydrometer, and if it be placed in a tall vessel of pure water, the oval part, together with a portion of the stem, will sink: a line, therefore, may be drawn upon the stem, corresponding with the surface of the water; and a number of equal divisions being drawn above and below this standard mark, the depth to which the stem sinks will show whether any other liquid into which the instrument is plunged, is lighter or heavier than water: thus, in alcohol, it would sink so low as to submerge nearly the whole of the upper stem, while in salt-water, it would rise so high as to leave the water-mark considerably above the liquid surface.

45. Before we proceed, we will again remind the reader, that the action of this instrument depends solely upon the displacement of a bulk of water equal to that of the submerged portion of the instrument; that the displaced liquid endeavours, so to speak, to recover its place, and does so by pushing up the solid (for in geometry a hollow ball is as much a solid, as if it were an unbroken mass of metal) which displaced it, and the solid is pushed up, until the effort of the water is balanced by the effort of the solid to sink. Equilibrium is now established, since the weight of the instrument, from the water-mark downwards, and the weight of the water displaced, are the same.

* This, however, is a very bad test, incapable of indicating the strength of brine; since an egg will float in a saturated solution of salt and water, and will also float, if, to the same saturated solution, a bulk of pure water equal to twice the bulk of the latter be added. According to Gay-Lussac, seven ounces and a half of salt are necessary in order to saturate an imperial pint of water at 60°; whereas if to this pint, two pints of pure water be added, the resulting solution will have a specific gravity of 1·078 at 60°, which is the average specific gravity of an egg at the same temperature. This is important; since the efficacy of brine in preserving meat depends very much upon getting a solution of salt at the exact point of saturation.

46. Philosophers have considered the particles of water to be round, and consequently to present a number of vacant spaces, or pores, since two spheres can only touch each other at one point; and that when a body is dissolved by water, such body enters into these vacant spaces or pores, and so increases the density of the whole. This theory, however, must be received with caution, inasmuch as we really know but little of the molecular constitution of matter; but, it is supported by some facts, which, as they are striking and applicable, we may briefly mention.

47. The solvent power of warm water is greater than that of cold, (with one remarkable exception, noticed by Dalton, viz., that more lime is taken up in solution by cold than warm water,) because, as warm water occupies more space than cold water, it is inferred that the globular atoms are in the former, removed to a greater distance than in the latter; and that, the spaces between the atoms being increased, the substance dissolved is taken up in larger quantity. In most cases, if the warm liquid be saturated with a soluble substance, a portion of the latter is thrown down in a solid state, as the liquid cools.

48. If a pint of sulphuric acid and a pint of water be mixed, the result will be considerably less than a quart; the same remark applies to strong spirit and water, and to many other substances among metals as well as liquids.

49. When a solid is dissolved in a liquid, the bulk of the latter is not always increased. Water will dissolve a portion of common salt, and afterwards another portion of sugar, without increase of bulk. A common illustration of this fact is to suppose a vessel filled with cannon-balls; the vacant spaces would evidently receive a large number of smaller shots; and the spaces formed by the latter would admit a portion of sand. Thus, the water having dissolved the salt, the particles of the latter being smaller than those of water, lie between them, as the small shots lie between the cannon-balls; and the particles of the sugar, being smaller than those of the salt, will, like the sand among the small shots, insinuate themselves into spaces too small for the admission of the salt. It is worthy of remark, that no substance ever dissolves in water without a change of temperature in the latter.

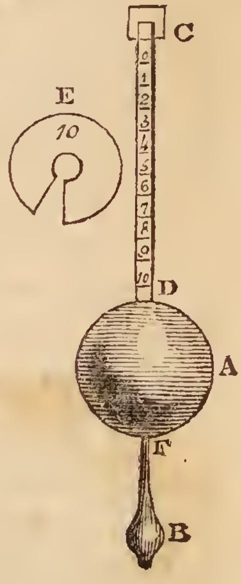
50. Aquatic plants have their pores round; and so are adapted, it is said, to receive the same shaped particles of water, upon which they live.

51. But, whatever may be the form of the ultimate particles of matter, one thing is certain, viz., that the density of the

fluid is increased by the addition of a soluble substance; and that, in proportion to the weight of the substance employed, the stem of the hydrometer will stand higher than in pure water; the scale of the instrument may also be so graduated, as to indicate precisely the quantity of solid matter suspended in the water. The methods of effecting this, we now proceed to detail.

52. The accompanying figure (4), represents *Sikes's hydrometer*, which is the one ordered by Act of Parliament to be employed in collecting the revenue on ardent spirits. It consists of a brass ball, A, whose diameter is $1\frac{6}{10}$ inch, into which is inserted a conical stem, F, about $1\frac{1}{8}$ inches long, terminated in a pear-shaped bulb, B, which is loaded, in order to give the instrument stability in water. At D is inserted a flat stem, $3\frac{4}{10}$ inches long, and graduated into eleven equal parts, each of which is subdivided into two. This instrument is accompanied by eight circular weights, such as E, in which a slit is cut, so as to admit the slender part of the conical stem at F into the hole in the centre of the weight, which then slides down to B. These weights are marked with the numbers, 10, 20, 30, 40, 50, 60, 70, and 80, and their use is to adapt the instrument to liquids heavier than water; because, without this, the ball would not sink low enough to allow the scale to be of service. When one of these weights is employed, the number marked on it must, of course, be added to that on the scale; but excise officers, in addition to the instrument, are furnished with a set of tables, accompanied by a few simple rules, by which the specific gravity of a spirit is easily ascertained when its temperature is known*; and for this purpose a thermometer always accompanies the instrument.

Fig. 4.



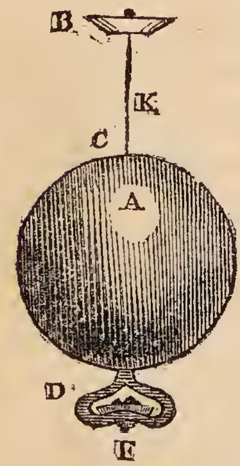
53. Another form of the hydrometer consists in having a second and smaller ball to screw to the large ball at F (fig. 4); this second ball is hollow, and, by means of shots within it, so

* So much is the specific gravity of alcoholic liquors affected by change of temperature, that a cubic inch of good brandy is ten grains heavier in winter than in summer, the weight in summer being four drachms thirty-two grains, and in winter, four drachms forty-two grains; so that thirty-two gallons of spirit in winter will measure thirty-three gallons in summer. Spirit-merchants, &c., seem aware of this fact, and contrive to make their large purchases in winter, and to effect their sales in summer.

adjusts the instrument as to cause the whole to weigh 4000 grains. The scale C D is graduated into inches and tenths of inches, and weights so low as tenths of grains are furnished, to be placed on the top of the stem at C, by which means the instrument may be brought to sink always to one certain division on the scale. Now, when the hydrometer is plunged into one kind of liquid, and a grain placed in C makes it sink one inch, the tenth of a grain would, of course, sink it only a tenth of an inch. If, therefore, it stand in one kind of water one-tenth of an inch lower than in water of another kind, it shows that a bulk of the former, equivalent to the bulk of the instrument, weighs one-tenth of a grain less than the same bulk of the latter water, which gives a difference in specific gravities between the two fluids of one part in 40,000.

54. *The hydrometer of Nicholson* (fig. 5) is an improvement upon one constructed by Fahrenheit, and is too important to allow us to pass by without giving it a particular description. It consists, as before, of a hollow brass or copper ball, A, fig. 5, to which, by means of an extremely thin steel wire, is attached a cup, B. A sort of stirrup, D, contains also a dish, E, and weights sufficiently heavy to cause the wire, C, to be vertical when the instrument is immersed in a liquid. The instrument is so adjusted, that when 1000 grains are placed in the cup, B, in distilled water at 60°, the whole sinks down to a point K marked on the wire. The quantity, therefore, of liquid displaced, is equal to the weight of the instrument below K, and 1000 grains in addition. Now it is quite clear, that if spirit at 60° be employed instead of water, a less weight than 1000 grains will suffice to sink the instrument to K; so that, knowing what this weight is, we get the weights of equal volumes of spirit and of water, and we obtain the specific gravity of the spirit, by dividing the weight of the spirit by that of the water; or by subtracting from 1000 grains the number of grains, which the spirit wants of 1000: as in par. 34.

Fig. 5.



55. By means of this hydrometer, the specific gravity of solids can be determined, as well as that of liquids. Let a portion of the solid be placed in the cup B, and as many weights as will sink the wire down to K: we know then that the solid and the weights together amount to 1000 grains; if, therefore,

these weights in grains be subtracted from 1000 grains, we shall get the exact weight of the solid in air. If now the solid be placed in the lower cup E, and the point K be brought down to the level of the water as before by means of weights, these weights, together with that of the solid in water, will again make up 1000 grains, and if the weights at B be subtracted from 1000, we shall get the weight of the solid in water: then, by dividing the actual weight in air by the difference of the weights in water and air, we get the specific gravity of the solid.

56. By means of this instrument specific gravities can be ascertained to within 100,000th part of their whole value, or to five places of decimals.

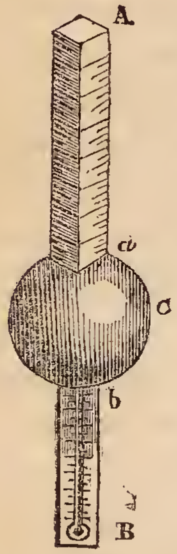
57. *The Arëometer** *of Parcieux* (fig. 6) is another form of the hydrometer. It consists of a glass phial or cylinder, B C, tightly corked, and into the cork is fixed a straight wire about 30 inches long. By means of shots contained within the phial the latter is made to sink in any liquid, so that about an inch of the wire above B is submerged. The liquor whose specific gravity is to be taken, is put into a cylindrical vessel E, three or four feet in height, and as many inches in diameter, and a scale of equal parts, D, is attached to the side to mark the degrees of immersion. The instrument is put into this vessel, and the specific gravities of various kinds of liquids are compared, as in the last case, by putting weights into the dish, A, until the instrument sinks down to a mark upon the wire. This instrument is so extremely sensible, that if contained in water of a given temperature, and the sun's rays be allowed to fall upon it for a few moments, it will sink through several inches, in consequence of the heat of the sun's rays diminishing the density of the liquid, and it will as quickly rise again if carried into the shade. A pinch of any substance soluble in water, thrown in, will cause it to rise, and a drop of strong spirit, poured in, will cause it to sink. One of these instruments weighs about 24 ounces, and in water there is a fall or rise of about half an inch for every $\frac{1}{17424}$th part of the liquid displaced; so that a difference in the specific gravities of any two liquids can be detected to the 100,000th part.

Fig. 6.

* A compound from the Greek ἀραιὸς, delicate, and μετρέω, to measure.

58. *Jones's Hydrometer* (fig. 7.) This instrument is intended expressly to indicate the strength of spirit; for which it appears well calculated. It is about nine inches long from A to B: C is a hollow globe about $1\frac{1}{2}$ inch diameter, and the stem A *a* is four-sided; the sides being graduated in a particular manner. The lower part, B *b*, is graduated and used as a thermometer, and made sufficiently heavy to keep the instrument upright. The limits of the instrument are from water to 74 degrees above proof,—that is, from water, containing no spirit at all, to spirit of that strength which is indicated by $\frac{74}{100}$ths stronger than the proof-spirit taken as the standard of the excise. The instrument is so adjusted that when placed in spirit 74 over proof, it sinks to the last graduated line near the top of the stem; and that when in spirit 47 over proof, it sinks only to the bottom of the stem at *a*. The space then from A to *a* is divided into 27 parts, which serve to indicate, by the depth to which the instrument sinks, all strengths from 74 to 47 above proof. These are engraved on one side of the stem, marked 0 at the top. A small weight marked 1 is then placed on the top, and the strengths measured by the use of that weight are noted on another side of the stem marked also 1. When placed in spirit 46 over proof, it sinks to the highest mark, and when in 13 over proof, it sinks to the lowest, at *a*. This space is divided into 33 parts, which, by the aid of the weight on the top, indicate all strengths from 13 to 46 over proof. The weight No. 1 is then replaced by a heavier weight marked 2, which is so regulated, that, with its addition, the instrument sinks to the upper mark in spirit 12 over proof, and to the lower mark in spirit 29 under proof. This third space is divided into 41 parts, which are engraved on the side marked 2, and with that weight proof-spirit is indicated, as well as all degrees to 29 under proof, and all to 12 over proof. This weight is then replaced by a third still heavier, which, in a similar manner to the instances before detailed, serves to indicate all strengths from 30 under proof to 100 under proof, which latter is, in fact, *pure water*. There are other marks on the stem, to indicate a remarkable effect produced by mixing spirit with water. If to 100 gallons of spirit 66 over proof, 66 gallons of water be added, it becomes of the strength designated as *proof-spirit:* but the bulk of the compound is not 166 gallons,—it is only 162, it having suffered

Fig. 7.



a condensation of 4 gallons in 166. If 61 gallons of water be added to 100 gallons 61 over proof, the loss is $3\frac{1}{2}$ gallons: at 56 over proof = 3 gallons: at 48 = $2\frac{1}{2}$ gallons: at 40 = 2 gallons: at 31 = $1\frac{1}{2}$ gallons: and at 12 = 1 gallon.

59. The lower stem has, on each side, a thermometer which shows what correction is to be made for temperature. Each of the two thermometers has two scales; so that there is a scale for each of the sides of the upper stem. The instrument is adapted for 60° Fahrenheit, and that temperature is taken for the zero of each thermometer, which is marked 0 in the middle of its height. The rest of the thermometer above and below is then graduated in a particular manner, each thermometer having a peculiar graduation of its own. If now the strength of the spirit be indicated by the stem and weight No. 2, look at thermometer No. 2, and if the mercury stand three divisions above the zero, subtract three degrees from the strength of the spirit: if the mercury indicate four divisions below zero, add four degrees to the strength of the spirit, and so on, with any height of the mercury, or any face of the instrument.

60. The practical applications of the hydrometer are very numerous, and the dependance which can be placed upon this beautiful instrument is, perhaps, the highest of its merits. The specific gravities of most substances in a state of purity are well known, and the taking of the specific gravity of any solid or liquid is often a sufficient test of its purity. No one, for example, could mistake between gold and copper-gilt; a simple appeal to the balance would detect the heavier of the two. The balance, however, would not detect pure gold from gold slightly alloyed with a baser metal; but by taking the specific gravity of the one and of the other, not only can the pure gold be decided on, but the exact proportion of alloy in the adulterated gold, and in many cases the real nature of the alloy, is ascertained by specific gravity alone. Spirits in every form and variety, as they occur in commerce, are a mixture of alcohol and water, and a few other bodies which determine the flavour, &c. of the liquid. Now, the value of these articles depends upon the proportion of pure alcohol contained in them; the purchaser does not want to buy water, for this he can easily and cheaply procure, and make the addition so as to suit his own profit or convenience. An amusing case of adulteration of spirit is mentioned by Dr. Arnott, in his *Elements of Natural Philosophy*. "A shopkeeper in China sold to the purser of a ship a quantity of distilled spirit according to a sample shown; but, not standing in awe of conscience, he afterwards, in the privacy of his store-house,

added a certain quantity of water to each cask. The spirit having been delivered on board, and tried by the hydrometer, was discovered to be wanting in strength. When the vender was charged with the intended fraud, he at first denied it, for he knew of no human means which could have made the discovery; but on the exact quantity of water which had been mixed being specified, a superstitious dread seized him, and having confessed his roguery, he made ample amends. On the instrument of his detection being afterwards shown to him, he offered any price for what he foresaw might be turned to great account in his trade."

61. The ignorance, manifested by this Chinese, of the application of the physical sciences, is perhaps natural and excusable; but what shall we say to the ignorance of an European nation, once so mighty in arms, arts, and literature, but now, alas! how fallen! The following account which was first mentioned by Dupin, places the commercial value of the hydrometer in a striking point of view.

"Brandies have, according to their greater or less degree of concentration, a greater or less specific gravity. The French, who first measured the degrees of concentration, by means of hydrometers, first gained by this means the advantage of being able to make their brandies always, and with certainty, of those precise degrees of strength which were required by the different markets to which they carried them. The Spaniards, whose strong full-bodied wines are eminently suited to distillation, endeavoured to enter into competition with the French in the sale of brandies; but as they are not acquainted with the method of measuring their degrees of concentration by means of hydrometers, they were obliged to content themselves with the following clumsy and awkward substitute. A drop of oil was allowed to fall from a given height on the surface of the brandy to be examined, and so as it was seen to sink in it, to a greater or less depth, the brandy was concluded to be of a greater or less strength. This measure failed them perpetually, and the result was, that their foreign market was supplied with brandies, on the strength of which no reliance could be placed. Spanish brandies having thus acquired a bad reputation in the market, they were purchased by the French merchants, concentrated to the requisite degree as shown by the hydrometer, and eventually resold as French. By the sale of this description of brandy in the Northern market alone, the French, before the Revolution, realized an annual profit of four millions of francs.

"The Spaniards now at length understand the use of the

hydrometer, and carry their brandies to market themselves."—Moseley, *Mechanics applied to the Arts*.

62. *The Lactometer**.—This instrument is only a modification of the hydrometer, and is employed to ascertain the specific gravity of milk, which is always somewhat heavier than water. In Switzerland and the north of Italy, the peasants sell the milk of their flocks to a large proprietor or cheese-factor, who receives it every evening, measures it, and ascertains its specific gravity. At the end of every season, each peasant receives, generally in kind, but sometimes in money, the value of his milk, according to the quantity and quality which is entered to his account by the proprietor. Thus the use of the lactometer prevents fraud; since the admixture of water would make the milk lighter, which levity the instrument, and the experience of the observer, would probably detect: but considerable error is likely to ensue, unless great precaution be taken in ascertaining the specific gravity of milk by means of the lactometer.

63. Cream is lighter than milk; so that milk rich in cream, and milk largely adulterated with water, would furnish equal results by this instrument. It has, therefore, been proposed to employ, as a lactometer, a graduated glass tube, filled with new milk, and allowed to repose for a certain number of hours; and then to note the thickness of the stratum of cream upon the surface, which will, of course, give the per-centage of cream in the milk. When all the cream is skimmed from off the milk which is to be tested, then the common lactometer will furnish the relative amounts of curd and whey; so that observations made by both instruments will thus furnish results tolerably correct: the one especially applying to the making of butter, and the other to the making of cheese.

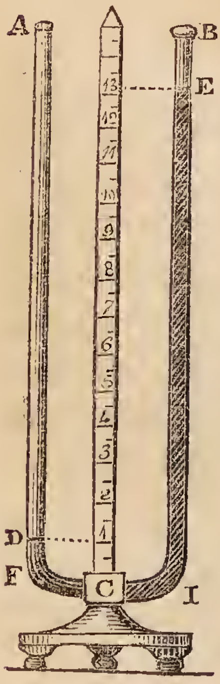
64. *The Saccharometer†*.—This, again, is only a hydrometer, applied to a particular purpose. It is known that beer, and malt-liquor generally is prepared from a grain, (barley is preferred on account of its affording a larger extract,) which, by being steeped in water for a few days, begins to germinate; it is then removed, and dried on a kiln; this constitutes malt, and during this process a saccharine principle is developed, which is also partly formed by, and is soluble in, water at about 170°. After a few hours' repose, if this water be removed from the

* More properly *Galactometer*,—compounded from the Greek γαλὰ *milk*, and μετρέω to *measure;* whereas *Lac* is the *Latin* name for *milk*.

* Σάκχαρ is the Greek word for *sugar*, and is here compounded as before.

grain, it will be found to be viscid and sweet, according to the quantity of malt employed. This liquor, which is heavier than water, is called *sweet-wort*, and the quantity of sugar or saccharine matter suspended in it is measured by means of the saccharometer, and thus the comparative values of different malts are estimated. This sweet-wort is boiled in a copper boiler, together with a vegetable-bitter, (hops afford the pleasantest bitter, and are therefore preferred,) for a considerable time; the liquor is then set aside to cool, and when it has cooled down to about 70°, a fermentable matter is added to it, called *yeast*, by which the whole mass is put into a state of active fermentation, which lasts generally three or four days, during which time a large quantity of carbonic-acid gas is thrown off; the liquor becomes specifically lighter, and from a thick, turbid appearance, which it had during active fermentation, it is now finer and more transparent, but it does not become altogether so for a few weeks. This process of fermentation is technically called *attenuation*, (from the Latin *tenuis*, thin,) by which a portion of the dissolved sugar is converted into spirit; and it is the amount of this latter which gives to malt-drinks the terms *strong* and *mild*. New beer is sweet, because little of the saccharine matter is converted into spirit; old beer is strong, for a converse reason. Now, it is of consequence to the brewer to know, from time to time, what progress his beers are making in the process of attenuation. This saccharometer tells him how much sugar is taken up to form spirit, and how much remains as *food* to what is left, as well as to impart or preserve flavour. This is important, since fermentation is always going on, more or less, in malt-drinks; and when all the sugar is taken up, and when the subsequent, which is called the *vinous fermentation* is at an end, the *acetous* begins, by which all his beer is converted into *vinegar*. Hence the sour taste of some beers, in which the acetous fermentation has begun.

Fig. 8.

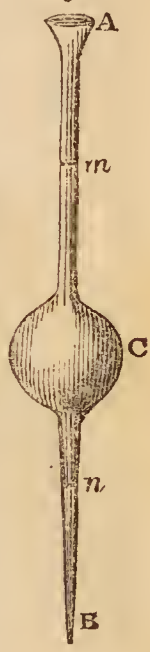


65. *The Barometrical Aëriometer* (fig 8).—This is an instrument which compares the specific gravities of immiscible liquids; but as the greater number of liquids will mix together, its application is limited. A siphon-tube, A B, is supported on a pedestal, C; the two ends, A and B, are open, and the two fluids, (say water and mercury,) are poured in. Suppose the mercury were poured in first, it would occupy the lower part of the siphon; but when water was poured into one leg, the mer-

cury would gradually rise in the other leg, until the line of division of the two liquids would be at C, the centre of the siphon. We should now know that equal weights of the two liquids were in the siphon, because they balanced each other. If now the height of the mercury from the level, (F I,) were an inch from F to D, the height of the water in the other leg, from I to E, would be about $13\frac{1}{2}$ inches; thus indicating that the densities or specific gravities of the two liquids were as $13\frac{1}{2}$ to 1. This instrument is of but little use for practical purposes, but the theory of its action will be sufficiently clear.

66. *Brewster's Staktometer**, or drop-measurer, (fig. 9,) is an instrument for measuring specific gravities by the size of the drops which exude from a small orifice. It consists of a stem, A B, the middle of which is expanded into a globe, C, half an inch in diameter. One point (m) is marked on the upper stem, and another point (n) on the lower stem. The vessel is then filled from B, by the action of the mouth at A, with distilled water, which is then allowed to flow out to the level, m. The number of drops which fall from the lower orifice is then reckoned from the level, m, to that of n; and that number, whatever it be, is taken as a standard. The instrument is then filled with proof-spirit, and the same process is observed as with water. Thus are furnished two numbers which form the extremities of a scale: when, therefore, a diluted spirit is poured in, the number of drops is intermediate between the two limits of this scale, and serves as an indication of the proportion between the aqueous and the alcoholic portions of the liquid. Thus, in one instrument, the number of drops of distilled water was 724, while the number with proof spirit was 2117; thus indicating that a drop of water was about three times the size of a drop of proof-spirit, and furnishing a scale of 1393 degrees to measure different strengths of gravity.

Fig. 9.



67. There is another mode of ascertaining the specific gravity of liquids, which, from its simplicity, deserves notice, although not susceptible of much accuracy. We have already alluded to an old-fashioned test of the strength of brine for pickling meat; and the employment of small, hollow beads with projecting tails, for ascertaining the specific gravity of liquids, seems to have been suggested by the use of the egg in the process above.

68. These beads were first employed by Professor Wilson,

* Στακτη, or σταξ, from the Greek, signifies a *drop*.

of Glasgow, and are so adjusted to each other, that one of them will remain at rest in any part of a fluid of a known specific gravity; the bead has a number marked upon it which indicates this specific gravity. A series of beads is thus prepared in a decreasing or increasing order from the specific gravity of pure water. When it is required to ascertain the specific gravity of a liquid, several of these beads are thrown into it; those which sink or swim are of no account; but that which remains suspended in the liquid shows the specific gravity. The success of this plan evidently depends upon the accuracy of the graduation of the beads.

69. This plan is adopted in sugar refineries with much advantage. Coarse, brown sugar is reduced to a syrup, and the impurities removed by a process of filtration; the syrup is then boiled, so as to concentrate it to a point at which it will readily crystallize into white loaf-sugar. To ascertain this point was once a difficult and uncertain matter; but now, by the employment of these beads, there is no difficulty in ascertaining the point of concentration at which the process of boiling must be stopped. While the syrup is weak, that is, while it contains much water, three properly adjusted beads are thrown in, which sink to the bottom. As the water evaporates, the syrup becomes more dense, and one of the beads rises to the surface. This warns the workmen to watch the process, as the syrup is near the strength required; the second bead soon rises, and then all the preparations are completed for drawing off, which is done the instant the third bead rises. The syrup is then placed in conical moulds to crystallize, and comes out in the form in which we see them at the grocer's shop.

70. Before we quit the subject, we must not omit to mention an elegant mode of determining specific gravities, first devised by M. Say, under the name of the *Stereometer**; and afterwards presented in an improved form by Professor Leslie by the name of the *Coniometer* †. The principles on which it depends are perhaps more philosophical than those of any other hydrometer. Its object is to determine the specific gravities of porous bodies, soft substances, and powders. If we take in the hand a piece of granite and a piece of Vesuvian pumice-stone, we directly say that the granite is much heavier, bulk for bulk, than the pumice-stone; but we must not forget that the pumice

* The word στερεὸς signifies *solid*, and seems to have been used to show that its action did not refer to fluids of any kind.

† From κονις, *dust*, or *powder*.

is full of cavities and pores, traversing it in every direction, and that we have obtained no information as to the absolute quantity of solid matter which it contains. This latter problem cannot be solved by the other hydrometers or hydrostatic balances; but Leslie's instrument measures the solid matter of such bodies with singular elegance.

A E is a glass tube about three feet long, two-fifths of an inch in diameter at the upper part, A B, and one-fifth at the lower part, B E; at B the tube is closed except a very small slit, too small to admit anything but air; at E it is open; the top, A, is ground smooth, to admit a glass plate being placed air-tight upon it; M is a glass vessel nearly full of mercury.

Fig. 11.

The powder, or porous substance, is put into A B, where it rests at B; the tube is then put into the vessel M until the mercury rises to B. The glass cover is then put on the top A, and thus the communication with the atmosphere is cut off both above and below. The part A B therefore contains the powder, and a certain, but unknown, quantity of air. The tube is then lifted up, until the mercury stands in it at half the height indicated by a common barometer at the time. Say that the latter is at thirty inches; thus the tube is to be elevated until only fifteen inches of mercury remain above the level of the mercury in M. But, in proportion as the mercurial pressure diminishes in elevating the tube, the air in A B will expand, the former being a consequence of the latter. Now that air was of the ordinary pressure (or thirty inches) when the plate was laid on the top; and, therefore, when the pressure from below is diminished from thirty to fifteen inches, the air expands to double its former bulk, and insinuates itself through the small fissure into the tube B E. We will suppose that the line of division between the mercury and air is now at C; then we may feel quite sure that the quantity of air in A B is precisely equal to that in B C, because the air is just half of its former density. The tube is then emptied, and again thrust into the vessel of mercury, and the plate is put on, while the part A B contains nothing but air. The tube is then elevated as before, until the mercury stands at fifteen inches in the tube; but in this case the air occupies a larger space than before: it reaches down, say to D, because there was more air to undergo the process of expansion than in the former case. Now a little reflection will show that the space C D is exactly equal to the actual bulk of solid matter

in the powder originally introduced into the instrument at A B; because, as B C was exactly equal to the space occupied by air in A B when the powder was present, and as B D is exactly equal to the whole space A B when the powder is absent, it follows that the space C D is equal to the solid matter of the powder or porous substance. The weight of a quantity of pure water equal to the space C D, having been ascertained, and likewise the weight of the powder in air, the specific gravity of the solid matter of the powder can be determined in the manner before detailed.

In conclusion, we may remind the reader, that, although such fluids as are so questionably named *non-elastic*, have certain properties distinct from the *eminently* elastic fluids, as air, &c., by which properties they are respectively recognised; yet, the former present us with properties common to fluids generally, and remind us of the all-pervading harmony in the productions of the material world; provided we bring to the study of them an enlarged and inquiring mind, and a sufficient share of correct sensibility to convert the general truths of Nature into her poetry. To study the wonderful and beautiful; to form even a faint idea of the Power, which can alone create; to contemplate with improved faculties the skill to digest, and the power and will to preserve, the Creation round;—all this opens to us the Almighty wisdom, and affords evidence, that the language of Poetry does not necessarily disagree with that of Truth; for the tendency of both is to elevate and enrich the mind by contemplating those pure models which prompted the poet's exclamation:—

> Oh Nature! all sufficient, over all!
> Enrich me with the knowledge of thy works!

IV.

THE HYGROMETER.

United, thus,
Th' exhaling sun, the vapour-burthen'd air,
The gelid mountains, that to rain condens'd
These vapours, in continual current draw,
And send them, o'er the fair-divided earth,
In bounteous rivers to the deep again,
A social commerce hold, and firm support
The full-adjusted harmony of things.—THOMSON.

1. THE expression of the Saviour of mankind, that "the rain falls both on the just, and on the unjust," reminds us of the wise ordination, whereby the physical laws which govern our globe, (and, by analogy, the universe,) depend in no way for their action upon the agency of man. On the contrary, they are entirely independent of him; and even subject him to their power. They extend their influence over him from the earliest dawn of his existence, until his animal-being terminates; and also then, the very laws which preserved his existence while alive, are now busy in decomposing and disposing of his remains, so as to render them useful in the great scheme of creation. Many of the grandest effects of Nature, many of her most extensively useful results, are effected by means often entirely invisible, save to the accomplished mind of the philosopher; and, so silent and stealthy is the action of these means, that the senses often fail to detect what the reasoning powers affirm to be present, and to have a wide range of action. Nature does not, perhaps, appeal to us so effectually through the senses, (save in their passage to the mind,) as through the mind itself; which, by the habitual contemplation and study of a perfect model, grows familiar with the attributes of the Source of Perfection itself, or to adopt the expression of the poet,

Thus the men,
Whom Nature's works can charm, with God himself
Hold converse; grow familiar, day by day,
With his conceptions; act upon his plan;
And form to his the relish of their souls.

2. A mind so formed resembles Nature more in her retired, than in her obvious, moods. The bustle, the glitter, the parade,

and the display of vulgar pleasures, such a mind shrinks from. But let it not be said that the retired habits, which study imposes, and to which inclination so well accedes, are productive of no results beneficial to the mass of mankind. It is, probably, to this very circumstance of men being found ready and willing to devote their lives (apart, as it were, from the world,) to study, whose ultimate object and aim is the extension of human knowledge, that our present high state of civilization is due, and its advance ensured. The prejudice is too common, which supposes, because there are some great men, whose habits of retirement prompt them to

> Do good by stealth, and blush to find it fame,

that they do not advance the dignity and happiness of our species, when compared with many who make it the business of their lives to augment their own importance by holding up to the gaze of the world, their own works, which, be they great or small, are often of more real importance to themselves than to science, although, like the meteor's glare, such works pass quickly away. On the other hand, the performances of the man of real worth, who is seldom solicitous for vulgar applause, may be compared to those mighty agents of Nature already referred to, which invariably and in silence perpetuate, from day to day, their useful operations, and which, to the world at large, would not be known to exist, were it not that sometimes their operation is partially suspended, inconvenience produced, wonder excited, and their importance then tacitly admitted by all.

3. These reflections have been suggested by the importance of our subject. By means of nature's distillation, water is always present in the air, where its paramount importance will be fully appreciated by referring to the Arabian desert, where sometimes the deadly simoom sweeps along in its course, destructive alike to men and to animals. The atmosphere, if literally dry*, would be entirely unfit for the support of animal or vegetable life :—therefore, by the exercise of a beautiful principle, nature constantly charges the air with vapour, in variable quantities; which it is the business of the Hygrometer † to detect and measure. This vapour forms clouds, hail, dew, and hoar-frost: by its means we get "rain from heaven and fruitful sea-

* It is usual in Germany, and those places where stoves and hot air-apparatus are employed, to place a pan of water in the apartment so heated, in order, by its evaporation—to supply the air with its necessary moisture.

† Compounded from the Greek ὑγρὸς, *moist*, and μετρέω, *to measure.*

sons," and that admirable variety throughout all nature, in various parts of the world, at different seasons, and at different hours of the day.

4. Our subject naturally divides itself into two parts. We shall first consider *Vapour;* the various circumstances under which it is produced, together with its properties: and our second division will include descriptions of Hygrometrical instruments, and the methods of employing them in Hygrometry.

Section I. On Vapour.

5. In our article on the Hydrometer (4) we distinguished gases from vapours, by showing that most of the former retain their elastic aëriform state under the influence of great pressure and intense cold; while a very moderate increase of pressure, or reduction of temperature, is sufficient to convert the latter into liquids, or even into solids. The distinctive character of gases and vapours consists solely in the relative forces with which they resist condensation.

6. One of the most important properties of heat, is that of converting liquid bodies into that rare, light, elastic substance, called *vapour.* It must not be supposed that the boiling-point of liquids must be attained before they can assume the vaporic form. Boiling or ebullition, is only one means, and generally speaking, an artificial means, of producing vapour. In this state the liquid is every where of the same temperature; as, also, is the vapour proceeding from it, provided it be not generated in a close vessel. In this state, also, vapour is formed from every part of the liquid, producing that commotion with which every one is familiar, and which is termed *boiling.* We see the vapour issuing from the spout of a tea-kettle, or from the surface of boiling water; and, because we do not see this effect from the surface of rivers, streams, or even from still water in our cisterns and water-jugs, it would be rash to conclude that they do not throw off vapour. It is true that water at 212°, and thence down to 60°, or even down to 32°, (the freezing temperature,) affords largely-decreasing quantities of vapour, during equal periods of time, which quantities depend entirely upon the temperature, as we shall presently show: but, that the vapour, so dispensed, is constantly present, not only from water in its ordinary state, but even from ice at any temperature, and that such vapour can be detected, and its quantity measured, will, we hope, be forthwith made clear.

7. During *ebullition*, we have said, vapour is formed from every part of the liquid. When vapour passes off only at the surface, the process is called *vaporization*. When the liquid is exposed to the atmosphere, and the vapour which rises is borne away by currents of air, the process is then called *evaporation*. This, however, appears, in the main, to be a distinction without a difference; unless we apply the term *vaporization* to the artificial process by which a liquid is kept at a constant temperature, and vapour produced, or the liquid dried up, in order to gain possession of any matters itmay hold in solution, as in the numerous instances of crystallization. In this view of the case, evaporation will be the natural process, whereby a liquid, at the natural temperature, gives off vapour into the air, the amount of which is detected and recorded by the hygrometer. In strictness, therefore, we should discuss in this place, the subject of *evaporation* only; but, as the two classes of phenomena are so intimately connected, that the details of one class are necessary to the explanation of those of the other, we shall discuss the two, in order.

8. I. *Vaporization*. If from a large glass vessel containing air and a very small quantity of water, the air be removed, the vessel closed, and heat applied, the liquid will soon disappear. But such liquids as sulphuric ether, or sulphuret of carbon, (whose boiling points are low,) may be employed without the application of heat. When the air is extracted they will disappear, (provided their quantity is not too great,) and the vessel will appear to be quite empty. But, such is not really the case; for, on continuing the application of heat in the first instance, and applying heat in the second, the vessel will burst into pieces with an explosion. By means of heat, and the removal of atmospheric pressure, the liquids are converted into transparent, invisible vapours, whose elastic for ceincreases under the influence of heat, to such an extent, as to resist the pressure of the sides of the vessel, which they force out, in virtue of their expansive power.

9. Or, if a glass vessel, capable of holding 100 cubic inches of mercury, and whose open end stands in mercury, be employed, and about 19 grains of water be sent up into the vessel, it will rise through the mercury, and occupy the highest part of the vessel, in consequence of its specific levity. If the whole apparatus be now raised to 212°, both the water and the mercury will disappear from the vessel. The latter will be full of the vapour of the 19 grains of water, which will occupy, in fact, 1689 times its former bulk.

10. Or, if a barometer tube, such as Fig. 2. in our article on the Barometer, be employed, containing mercury, and a few drops of water, and standing in mercury as in the figure, the water will rise up to the surface of the mercury, and will have above it no fluid whatever, except its own vapour, whose elastic tendency will be to depress the mercury in the tube. The amount of this tension or elasticity may be measured by comparing the height of the mercury in the tube with that in a good barometer near it; and the temperature of the water, and of its vapour, may be determined by surrounding the upper part of the tube with a vessel containing water and a thermometer. It is obvious that the water on the outside, and the water and vapour within, will have the same temperature. If the barometer stand at 30 inches, and the mercury in the tube at 29 inches, then the tension or elastic force of the aqueous vapour will be expressed by one inch of mercury, or $\frac{1}{30}$th part of the elasticity or tension of the atmospheric air.

11. In our second illustration, where the water is heated to 212°, if the vessel employed be a barometer-tube, the whole of the mercury would be forced out into the reservoir below; and we should find that the tension of the vapour would equal the mean pressure of the atmosphere at the level of the sea in this country; that is to say 30 inches of mercury. So also, as the atmospheric pressure is 30 inches of mercury, an atmosphere of steam, of the temperature of 212°, would support the same height of mercury.

12. As water is converted into vapour at all degrees of temperature, even at 32° and lower, copious tables have been constructed by accurate observers, indicating the elastic force of vapour at all temperatures. The following is a specimen of such a table:—

Temp.	Force of vapour of water in inches of mercury.	Temp.	Force of vapour of water in inches of mercury.
—40°	0·013	90°	1·36
30	0·020	100	1·86
20	0·030	110	2·53
10	0·043	120	3·33
0	0·064	130	4·34
+10	0·090	140	5·74
20	0·129	150	7·42
30	0·186	160	9·46
32	0·200	170	12·13
40	0·263	180	15·15
50	0·375	190	19·00
60	0·524	200	23·64
70	0·721	210	28·84
80	1·00		

Temperature.	Force of vapour of water in inches of mercury. Dalton.	Ure.
212°	30·00	
220	34·99	35·540
230	41·75	43·100
240	49·67	51·70
250	58·21	61·90
260	67·73	72·30
270	77·85	86·30
280	88.75	101·90
290	100·12	120·15
300	111·81	139·70

13. We see, from these extracts, how rapidly the elasticity increases with the temperature. We are all familiar with the surprising results obtained in the arts, by employing, as a motive power, the elastic force of steam, particularly at high pressures, where as the above table shows, at 250°, it will support a column of mercury from 58 to 61 inches in height, and at 300°, the height of such a column would be from 111 to 139 inches. No law has yet been discovered respecting the increase of elasticity with given increasing ratios of temperature: indeed, the discrepancy between the observations of Dalton and Ure, and between those again and the observations of Dulong and other French philosophers, sufficiently prove that the subject is as yet far from being well understood.

14. The elastic force of other liquids, such as sulphuric ether, alcohol, liquid-ammonia, sulphuric acid, and mercury, has also been ascertained by Dalton, by means of the simple apparatus contrived by him. From these observations he inferred that the temperatures and corresponding pressures of the vapours of different liquids, had a relation, which may be thus expressed;—the same increase of the temperature of a liquid will always increase the elastic force of its vapour in the same proportion; and this is true of different liquids, as well as of the same liquid.

15. We may observe, by way of illustration, that the elastic force of vapour of water at 212°, and that of alcohol at 173°, are respectively equal to a column of 30 inches of mercury; the difference between these two temperatures being 39°. The elastic force of vapour of water at 190° is equal to 19 inches of mercury, and $190° - 39° = 151°$, at which temperature the vapour of alcohol is also equal to 19 inches of mercury.

16. If this law be true, it follows, that when the tension of the vapour of water at all temperatures is accurately determined, we can readily ascertain the tension of the vapour of any other liquids, simply by knowing their boiling-points. For example,

ether boils at 96°; and the difference between its boiling-point and that of water is 116°. If the elastic force of the vapour of ether at 200° be observed, we shall have that of the vapour of water at 316°; and if the tension of the vapour of ether be observed at 300°, we shall know the tension of aqueous vapour at 416°. In this way the elastic force of steam, at unattainable temperatures, may be determined by experiment on another liquid, whose boiling-point is considerably lower.

17. It is also a consequence of this law, that liquids which boil at very high temperatures, produce vapours of no sensible pressure at ordinary temperatures. Sulphuric acid boils at 620°, which exceeds boiling water by 408°. Sulphuric acid, therefore, at 440° will have a vapour of the same tension as water at 32°, which is equal to $\frac{2}{10}$ths of an inch of mercury;—it follows, therefore, that at ordinary temperatures Sulphuric acid affords no appreciable vapour.

18. The application of this law to barometrical observations is very important. Mercury boils at about 450° above the temperature of boiling water:—the tension of its vapour at all ordinary temperatures must therefore be quite inappreciable. But it has been proved beyond doubt, that, in the Torricellian vacuum, above the surface of the mercury vapour is always present:—as however its tension must be inappreciably small, it follows that its force, counteracting the atmospheric pressure, amounts, in practice, to nothing.

19. This law of Dalton has excited much discussion, which has shown difference of opinion among philosophers; and even Dalton himself does not seem to insist upon its accuracy.

20. Many solids emit vapours of no appreciable elasticity. Camphor slowly disappears, if left uncovered. Tin, brass, lead, &c., by their odour, prove that they also exhale vapours. These, and other solids, such as arsenious and benzoic acids, are converted into vapours at a much lower temperature than is required to melt them.

21. The specific gravities of several vapours have been determined with great care by Gay Lussac. These specific gravities are referred to that of air, which is taken as unity when heated to the boiling-point of each liquid. But, in the second column, we cannot compare the specific gravities with each other, since the standard of comparison varies with the boiling-point of each liquid: the third column, therefore, exhibits the actual specific gravities of the vapour of each liquid, as referred to the specific gravity of air at 60°; and the fourth column gives the respective boiling-points of the liquids.

	Sp. gr. at boiling-point, air heated to boiling-point being 1.	Sp. gr. at boiling-point, air at 60° being 1.	Boiling-points.
Water	0·6235	0·481	212°
Alcohol	1·6030	1·311	173
Muriatic ether	2·219	2·255	52
Sulphuric ether	2·586	2·415	96
Bisulphuret of Carbon	2·6447	2·376	116
Oil of Turpentine	5·013	3·342	314
Hydriodic ether	5·4749	4·666	148

22. Vapours, in common with other substances, expand by heat, and contract by cold. It has been ascertained by Biot and Arago, that water at 60° increases 1689 times its volume on being converted into steam at 212°; alcohol 493·5 times its volume, in passing from 60° to its boiling-point; and sulphuric ether 212·18 times. From a comparison with various other liquids, it appears that, when water is converted into steam, it is subject to a much greater expansion than any other liquid yet examined. It expands eight times as much as sulphuric ether, and nearly three and a half times as much as alcohol. This explains the remarkable fact, that the vapours of alcohol and ether are heavier than that of water; although the liquids themselves, which produce the vapour, are lighter than water. This fact may be illustrated by a very pleasing experiment. Procure two glass goblets of equal capacity, and into one of them let fall four or five drops of sulphuric ether. By giving the glass a slow and oblique rotatory movement, the whole of the liquid may be spread over the interior surface of the vessel. The liquid will soon disappear, and the vessel will be filled with vapour of ether, to the exclusion of the atmospheric air, which previously occupied it. If the mouth of this glass be brought near to that of the other, the vapour may be poured from the first into the second glass; as may be proved by applying to the latter a lighted taper, which will ignite the vapour; whereas it will produce no effect, if applied to the first glass, into which the ether was originally poured.

We do not propose to discuss in this place the theory of steam, or the conversion of liquids into elastic fluids; but refer our readers to our article on the thermometer.

23. When several gases, which have no action upon each other, are mingled together in the same vessel, the elastic force of the mixture is equal to the sum of the elastic forces which the gases respectively possess; so that, if one volume of atmospheric air, exerting the pressure of one atmosphere, or 15 lbs. on the square inch, be mixed, without change of bulk, with another volume of atmospheric air exerting the same pressure,

the result will be a pressure of 30lbs. on the square inch. The same law applies to the mixture of vapours and gases. Provided they have no chemical action on each other, the elastic force of the mixture is equal to that of the vapour added to that of the gas; that is, a vapour, though mixed with gas, preserves its elasticity unchanged; and the two bodies behave, under all changes of volume, by compression or rarefaction, precisely as they would have done, if each separately occupied the same space.

24. In our article on the Hydrometer (14), we stated that airs expand $\frac{1}{480}$th part of their volume at 32°, with every degree of Fahrenheit's thermometer. The same rate of expansion applies to vapours; so long as no parts of them are allowed to be condensed into the liquid form. This law also applies to mixtures of vapours and gases. In all these cases, if the aëriform bodies be not allowed to expand, they receive equal increments of tension for equal increments of temperature.

25.—ii. *Evaporation.* As we have already stated that water evaporates at all temperatures, the reader will easily call to mind numerous instances of spontaneous evaporation, even in the course of his daily observation. A shower of rain, which thoroughly wets the streets and pavements of a city, is soon dried up, or *evaporated*, in warm, or windy, weather. Ponds become dry in summer, and rivers shrink within their beds, from the same cause. Wet linen, hung out to dry, soon parts with its moisture; and the ink, with which we write, soon parts with the colourless liquid, which held in solution the colouring matter now left behind in a solid form upon our paper.

26. As it is by extending the principle of small to grand effects, and by the application of a known cause to all such effects, that we generalize, we may instance the enormous daily evaporation, which keeps within its limits the Mediterranean Sea. This inland sea is the recipient of many mighty rivers—the Nile, the Po, the Rhine, the Ebro, the Danube, the Dnieper, the Don, and others of less note; while the Atlantic always flows in through the Straits of Gibraltar: a proof that evaporation dissipates more than all the quantity of water thrown into it from a vast portion of Europe, as also from parts of Africa and Asia. The large tracts of land by which it is surrounded on the south, north, and east, waft their winds over its surface in a comparatively dry state, which causes a constant and quick amount of evaporation, and thus accounts for the expenditure of the large quantity of water, which it receives from the many rivers flowing into it.

27. It is only within a few years that we have been in

possession of a rational theory of evaporation. Our illustrious countryman, Dalton, to whom we are indebted for most of the details of the present article, is the author of the modern and accepted theory. But before we explain it, we will give a short account of the old theory; which we are tempted to do, if only for the sake of adding lustre, by comparison, to the adopted theory.

28. It was supposed that vapour at a low temperature, compared with that at a high temperature, possessed properties essentially different, the one from the other. Above all, it was supposed that vapour at a low temperature possessed no elasticity. Halley thought that water is dissolved by air in a manner similar to sugar, or salt, or any substance which is soluble in water. In this way it was sought to be explained why water evaporated so quickly in warm and windy weather. Wind produced agitation, and so promoted the solution, or brought up fresh currents of air to take up more vapour. Heat, also, it was said, increased the solvent power of air, in a manner similar to that by which it is known to increase the solvent power of water on salt, sugar, &c.

29. But, when it was shown that vapour at all temperatures possesses elasticity, and that air, so far from promoting evaporation, actually retards it by its presence, and that liquids evaporate more quickly and completely *in vacuo* than in air, this theory was repudiated. Thus, another instance was added to the many which previously existed, and which still continue to exist, of the fallibility of too rapid a generalization. Such instances as these ought to caution the student not to be eager to theorize. In science, as in morals, falsehood too often assumes the garb, and apes the manners, of truth; is plausible and self-sufficient for a season; but will not stand the test of time, nor bear the scrutiny of the true disciples of Nature. Besides, to deal in hypothesis is exceedingly easy, and affords no proof of a philosophic mind; since a quick, and ready habit of thinking, may induce many an individual to guess at a cause, and this guess may soon be inflated into a well-looking theory. But the inductive philosopher is not so readily satisfied; the calm investigation, the diligent inquiry, the unremitting search after facts, and the untiring repetition of experiment after experiment,—all these, and more, are the precursors to a theory laid out by such a man; all these, and more, were employed in the instances before us; and such a man is our countryman, Dalton.

30. Heat, then, is the cause of evaporation at all temperatures; the rated amount of evaporation depending upon the temperature. Also, the facility with which liquids evaporate,

depends greatly upon their boiling-points. Thus, if we place in open vessels of the same size, equal bulks of water, alcohol, sulphuric ether, sulphuric acid, and mercury, and leave them for a time quite undisturbed, at the ordinary temperature of the atmosphere, we shall find that the ether will have disappeared first, then the spirit, then water; that the sulphuric acid has actually gained in bulk by absorbing water from the air, and that the mercury has not suffered any appreciable diminution. Now, all these fluids boil at various temperatures, and disappear or pass off in vapour, in the ascending order of their boiling-points. The fixed oils do not evaporate sensibly until about 600°; and even then, the vapours arising from them do not properly belong to them, since, at that temperature, these vapours acquire properties not belonging to the oils whence they are derived. If an evaporable liquid have its surface covered with oil, spontaneous evaporation is entirely suspended.

31. But, as most of the circumstances which attend the evaporation of water, apply also to other liquids, we shall confine our attention principally to water.

32. Evaporation, as we have already stated, is confined to the surface of liquids. So that a certain quantity of water will disappear much more quickly in a broad, shallow vessel, than in a deep, narrow one. So, also, if the surface be agitated by wind, the evaporation will proceed more quickly, and still more so in proportion as the wind is warm and dry. But, when the air is at rest, the vapour, as it forms, accumulates over the surface of the water, and diminishes sometimes to nothing the succeeding evaporation.

33. Evaporation also increases with the temperature. Ice and snow are constantly giving out vapour; so that, in a cold, dry atmosphere, they rapidly diminish in bulk. *In vacuo* the evaporation is accelerated, especially if any substance be present (such as sulphuric acid), which will absorb the vapour as fast as it is formed. In this way two or three ounces of ice, at a temperature considerably below 32°, will disappear in the course of twenty-four hours.

34. By observing the rate at which water at different temperatures evaporates from a vessel of a certain diameter, the quantity evaporated in a given time, at every temperature from 0° to 212°, can be determined, supposing, in the first instance, that the atmosphere in which the evaporation is going on is dry. Dalton found that the rate of evaporation was always proportional to the elasticity of the vapour generated. So that the quantity evaporated from a given surface at the following tem-

peratures, is expressed in the second column of the following table:—

Temperature.	Rate of evaporation.	Temperature.	Rate of evaporation.
212°	512	79·5	16
180	256	58	8
150	128	38	4
125	64	18·5	2
100	32		

At low temperatures, however, this law admits of some modification; because the vapour already suspended in the air soon interferes to check further evaporation. Another mode was therefore adopted by Dalton for low temperatures, which we will detail in our second section.

35. *In vacuo*, water and other liquids evaporate with great rapidity. Indeed, if a liquid be suddenly introduced into a vacuum, its vapour instantly fills it; and, provided such vapour be removed as it is formed, the liquid is soon dissipated. So copious is the discharge of vapour, *in vacuo*, from some bodies whose boiling-points are low, that they boil with great rapidity at temperatures far below that of freezing water. If water be placed in a flat dish, and ether be poured upon its surface, and the whole be covered with a glass receiver on the table of an air-pump; as the air is being rarefied, the ether will soon begin to boil, and so much heat is abstracted from the water to form vapour, that the water will be converted into a solid lump of ice. Thus, we have the singular spectacle of two liquids, one upon the other, the upper one boiling and the lower freezing at the same time.

36. Water at about 80° will boil rapidly *in vacuo*, in consequence of the rapidity of evaporation.

37. If sulphuric acid be placed in a broad flat vessel, and water at the ordinary temperature be placed in another vessel above the first, and if the air be extracted, vapour will speedily rise from the water, which vapour will be absorbed by the sulphuric acid as fast as it is formed, and the water will speedily be frozen. This beautiful experiment is due to Leslie, who also succeeded in freezing mercury by similar means. In this state it was solid, and its temperature − 120°.

38. So also, by wrapping some cotton wool round the bulb of a thermometer upon which the sun is shining, and pouring ether upon it, the evaporation of the liquid will produce cold, and sink the mercury in the tube considerably below that contained in another thermometer standing in the shade.

39. As it has been supposed by philosophers that there is a limit to the atmospheric air, and that this limit is within about

forty-five miles of vertical height from the surface of the globe, so, by analogy, it has been reasoned that a limit to vaporization must also exist. With respect to the limit of the atmospheric air, Dr. Wollaston observed that the tendency of the molecules of the atmospheric air to repel each other, being known by direct observation to be subject to a continual diminution in proportion to the rarefaction of the air by diminished pressure, whereby the distance between the molecules of the air is increased; and these molecules being subject, like all matter, to the laws of gravitation; it follows that when the actual weight of the molecules becomes equal to their mutual repulsion, then, these two forces balancing each other, the molecules will rest altogether like the particles of a liquid. This must happen, therefore, on the top of the atmosphere, where it is possible to conceive a body, whose specific gravity is less than the specific gravity of air in that state of rarefaction, in which the repulsion of its molecules equals their weight, to float on the surface exactly in the same manner, and for the same reasons, as a ship floats on water; or to come to a closer analogy, for the same reason that we see a balloon float between two strata of air, when, bulk for bulk, it is lighter than that on which it presses, and heavier than that immediately above it. If it be admitted that the tendency to evaporation depends on the energy of the repelling force produced by the presence of heat, which force tends to drive off the stratum of particles which rest on the surface of the liquid, it will follow, that gravity will at length balance or prevail over the repulsive force, and will prevent the particles from flying off, or evaporating. Immediately before the liquid attains this state, the repulsive principle exceeds the gravitating one by so exceedingly small an amount, that the quantity of evaporation, though not exactly nothing, may be conceived to be so extremely small, as to be insensible to observation. It is probable, then, that the less vaporizable substances, at common temperatures, are below the limit of vaporization; and that, of vaporizable substances, the atmosphere contains chiefly aqueous vapour, and that the presence of other vapours from volatile substances is only accidental and occasional. Dr. Faraday, who thus applied Dr. Wollaston's theory, found that mercury, at a temperature varying from 60° to 80°, yields a small quantity of vapour; but in winter no trace of vapour could be detected. The method adopted to ascertain this fact was to place the mercury in a bottle, and to cover the under surface of the stopple with gold leaf, or some other metal, which has a great affinity for mercury. In this way, the smallest trace of vapour of mercury could be detected

by the stain it would leave on the surface of the gold; and the distance between the surface of the mercury and of the gold could of course be varied by employing bottles of different heights. Dr. Faraday has also proved that several other chemical agents, kept in a confined space with moisture, during four years, did not undergo the slightest evaporation. The method for proving this was as follows:—Several stoppled bottles were made perfectly clean, and several wide tubes (closed at one extremity, so as to form smaller vessels capable of being placed within the bottles), were prepared. Selected substances were then put into the tubes, and solutions of other selected substances into the bottles; the tubes were placed in the bottles, so that nothing could pass from the one substance to the other, except by vaporization. The stopples were introduced, the bottles tied carefully over, and put away in a dark, safe cupboard, where, except for an occasional examination, they have been left for nearly four years; during which time, such portions of the substances as could vaporize have been free to act, and produce an accumulation of their specific effects.

"The first bottle contained a clear solution of sulphate of soda, with a drop of nitric acid; the tube contained crystals of muriate of baryta. One half or more of the water has passed by evaporation into the tube, and formed a solution of muriate of baryta above crystals; but both that and the remaining solution of sulphate of soda, is perfectly clear; there is not the slightest trace of sulphate of baryta in either the one or the other, so that neither muriate of baryta nor sulphate of soda appears to have volatalised with the water.

"Another bottle contained a solution of muriate of lime; and the tube, crystals of oxalic acid. The water here remained with the muriate of lime. In the tube, the oxalic acid, when put in, had formed a loose aggregation, with numerous vacancies, and with a very irregular upper surface, about an inch below the upper end of the tube. No particular appearances occur in the vacancies; but at the top there has evidently been a sublimation of oxalic acid, for upon the crystals and glass, new crystals in exceedingly thin plates, and reflecting colour, have been formed: these rise no higher in the tube than to the level of the most projecting part of the original portion of oxalic acid; no appearance of sublimation is evident above this, and it seems as if the most elevated parts of the salt have given off vapour which has sunk, and formed crystals on the neighbouring lower surfaces; but that no vapour has risen to the upper part of the tube. On examining the solution by a drop or two of pure ammonia, it was, however, found that a slight precipitate of

oxalate of ammonia occurred. The experiment shows, therefore, that oxalic acid is volatile at ordinary temperatures, and had not only formed crystals in the tube, but had passed over to the solution of lime."

40. In this way Dr. Faraday proceeded with eighteen bottles; but the particulars of the results we need not give. In nearly all the cases, however, a portion of the water, forming the solution of one substance, had passed over into the other in the form of vapour;—thus showing that the other bodies might have done so likewise, if the temperature had permitted.

41. These experiments were instituted, partly, to determine whether water, or its vapour, confers volatility, even in the slightest degree, upon those substances which alone have their limits of vaporization at temperatures above ordinary occurrence:—an opinion to that extent having been entertained; but Dr. Faraday thinks the above experiments disprove it.

42. It appears, however, from some of Dr. Faraday's experiments, that "Nitrate of ammonia, corrosive sublimate, oxalic acid, and perhaps, oxalate of ammonia, are substances which evolve vapour at common temperatures."

43. It is to evaporation and condensation alone, that we owe the various natural phenomena of fogs, clouds, rain, dew, snow, hail, and hoar-frost,—the incomparable beauty and utility of which ill deserve the hasty notice with which we must dismiss them. The supply of sap and juice to vegetables, and of liquids to animals, is necessary to ensure their very existence. The pure liquid which is obtained from the surface of seas, lakes, and rivers, (as also from great part of the land itself,) in such abundant quantities, by an unceasing process of distillation, is dismissed into the atmosphere and wafted by the wind around the whole globe. By a reduction of temperature, the air is sometimes saturated with vapour,—the particles coalesce, and, forming spherical drops, descend as rain. If this coalition take place in high regions, where, in consequence of rarefaction of the air, great cold exists, the drops are frozen, and hail is the natural result. But from some unknown cause, it frequently happens that the condensed vapour does not unite into drops; but is formed into vesicles, which are lighter than the air. These vesicles, being all in the same electrical state, are held at a certain distance from each other by the principles of electrical repulsion, whereby they are prevented from forming into drops. Thus, being more or less opaque, and floating in the air, they form all the unceasing variety of clouds. When

these vesicles become frozen, they often fall in the form of snow.

44. As the sun, during the day, is shining upon and heating the earth; and by producing evaporation therefrom, is acting so as to supply the air with large quantities of vapour of a temperature so elevated as to prevent saturation, and consequently condensation;—and as those parts of the earth which reflect least heat, absorb most,—so, when that luminary is below the horizon, the heat so absorbed is returned back into space, by a process, which is called *radiation*. In proportion, then, as radiation is great, the radiating bodies are cooled below the temperature of the superincumbent air, and are in a condition to condense the vapour suspended therein. Accordingly, the vapour, by reduction of temperature, attains, and even passes beyond, the point of saturation, and falls in pellucid drops upon the surface of the ground, upon plants, and upon vegetables, in the form of *dew*. By a beautiful reservation, too, those bodies, which require the liquid nourishment most, radiate heat in the greatest proportion, and consequently receive most dew: such bodies are soils and all vegetables: whereas, those surfaces which need no moisture, such as gravel-walks, roads, stones, &c., radiate but little, and consequently the dew falls but sparingly upon them, while it exists in abundance upon the neighbouring vegetable surfaces. Should the temperature fall to, or below 32°, the dew is frozen, and then *hoar-frost* is the result; which bears the same relation to dew as hail does to rain. We have also, in the process of the formation of dew, another instance added to the many already before us, of the admirable economy of Nature. On cloudy nights, when the air contains, necessarily, more vapour than on clear nights,—the radiation of vegetable surfaces is checked by the reflection of the heat from the clouds back to the surface of the earth, whereby the temperature of the latter is but slightly reduced, and on such occasions very little dew is produced, because plants do not require its aid in a moist air.

45. When vapour is abundant near the surface of the earth, and by a sudden reduction of temperature, as by a change of wind producing an admixture of cold air with the vapour, the latter is partially condensed, so as to become visible,—a *fog* or *mist*, is the name attached to it.

46. The rain, which falls upon the earth, is in great measure absorbed; and finding its way into channels under its surface, forms wells and underground currents of water: when these issue from the earth they constitute springs and brooks,

or, collecting from many sources, form mighty rivers and lakes; and at length discharge themselves into the sea, diffusing freshness, health, and plenty in their course. Again and again, in a perpetual round, do these processes take place, rendering this world the delightful abode which it appears to be to the cheerful mind, which can behold the phenomena of nature and agree with the Poet of the Seasons, as expressed in our motto, that they

> A social commerce hold, and firm support
> The full-adjusted harmony of things.

47. We have now stated the principal phenomena which attend the production of vapour: we have detailed the beautiful theory, by which such phenomena are accounted for: and we have briefly applied it to the production of certain natural phenomena. We now proceed to show how well this theory explains numerous processes in science, and in art.

48. The whole of the practice and art of distillation depends upon the principle of evaporation and condensation. When it is desired to separate one liquid from another, or a liquid from a solid, evaporation is conducted in close vessels. For example:—if we wish to convert a quantity of hard water into soft by the process of distillation, the hard water is boiled in one vessel, to expel all the gases; and then its steam is made to pass into a second vessel, which is kept constantly cool, whereby condensation takes place, and pure water is obtained: or the steam is conducted through a pipe contained within a tub of cold water, and curled several times. The curled pipe is called *the worm*, which, with the vessel of cold water, has the general name of *refrigeratory* or *cooler*. Hard water is distinguished by the presence of certain mineral substances, such as carbonate or sulphate of lime, the acid of which, uniting with the alkali of soap, decomposes it; and the fatty part of the soap, uniting with the lime, forms a white curdy matter, insoluble in water. In soft water, however, soap dissolves perfectly; and it will be seen that, by distillation, vapour of water only is raised and condensed; since it is clear that the mineral bodies, which rendered the water hard, do not form any vapour at the boiling-point of water, and consequently are not carried over with the vapour of water into the refrigeratory, but are left behind with the boiling water.

49. By distillation, spirit may be almost, (but not completely,) separated from water. If a mixture of alcohol and water, in equal parts, be raised nearly to the boiling-point of the spirit, a vapour will rise, composed of vapour of water and

vapour of spirit, mixed. Now, as the density of vapour of alcohol, at its boiling-point, is about $3\frac{1}{2}$ times that of vapour of water at 212°, and as the density of vapour of water at 212°, is double the density of vapour of water at 180°, it follows that the density of vapour of alcohol at 180°, (its boiling temperature) will be about 7 times the density of vapour of water at that temperature. So that in the vapour produced from an equal mixture of alcohol and water, the proportion of alcohol to water is as 7 to 1. This, by condensation, affords a very strong spirit; and, by repeated distillations, may be more and more separated from its contained water.

50. As liquids boil at very low temperatures, *in vacuo*. recourse has been had most successfully to the preparation of vegetable and other extracts employed in medicine, by boiling them *in vacuo*. The usual mode of preparing extracts, formerly, was to evaporate the vegetable juices in open vessels; but the product in this case was uncertain, and often bad, in consequence of the tendency of the active matter of the juices to decompose, when heat, such as that of boiling under pressure, was employed, or when they were subjected for a long time to the action of the atmospheric air. Such juices were, by the improved process, evaporated *in vacuo*, at a heat not exceeding 100°; and in this way, they were boiled and concentrated without any loss of medicinal virtue. The same process has been adopted in sugar-boiling. The syrup being evaporated *in vacuo*, is brought to the point of crystallization without any risk of burning it, injuring its colour, or decomposing it; and at the same time the occupation is entirely free from the numerous accidents by fire, which formerly rendered the neighbourhood of a sugar-refinery unsafe. Sugar, refined in this way, is called *vacuum-sugar;* and is distinguished by its hardness and whiteness, while its price is even lower than the sugar prepared by the ordinary process of boiling.

51. Whenever vapour is formed, it is, as we have already seen, by depriving the liquid, to which it is due, of more or less of its heat; or by abstracting heat from surrounding objects. But a depression of temperature is the usual result in every substance which furnishes vapour. In this way water and wine are cooled in the East, by means of certain porous vessels, called *alcarrazas*, which being filled with water, and hung up in a current of air,—the fluid, penetrating slowly to the outside of the vessel, is converted into vapour by robbing the interior water of a portion of its heat; and thus the cooling

effect is produced. If the wine-bottle be placed in the cooler, its temperature is lowered with the water.

In India, ice is obtained by a similar artificial process. Large and shallow excavations, about thirty feet square and two feet deep, are made in open plains; in which water, placed in unglazed, porous vessels, is left to evaporate in the evenings of the months of December, January, and February. Between the water-vessels and the earth, is placed a layer (about a foot in depth,) of sugar-canes, or dried stalks of Indian corn. In the mornings, the ice, which had formed during the night, is collected, and deposited in pits 15 feet deep, and surrounded by straw and other non-conducting bodies; and is so stored for use.

In the absence of ice, wine may be cooled by wrapping a wet towel round the bottle, and exposing it to the sun. The evaporation of the water cools the wine. In the East, travellers keep the water cool by wrapping the jars in linen cloths, kept constantly wet.

In India, the bed-curtains are sprinkled with water, by the evaporation of which the air within is cooled.

52. Sea-salt is obtained by spontaneous evaporation. A number of shallow, oblong pits are dug along the west coast of France, and on the south coast of England. These pits are lined internally with clay. The sea-water is allowed to flow into them: and in summer the water evaporates quickly, leaving the salt behind in dry crystals. This salt is called bay-salt, and is preferred to every other in the curing of fish.

53. In some manufactories, where fluids are evaporated on a large scale, it is found more economical to pass a brisk current of hot air over the surface of the liquid, than to apply heat to the bottom of the vessels.

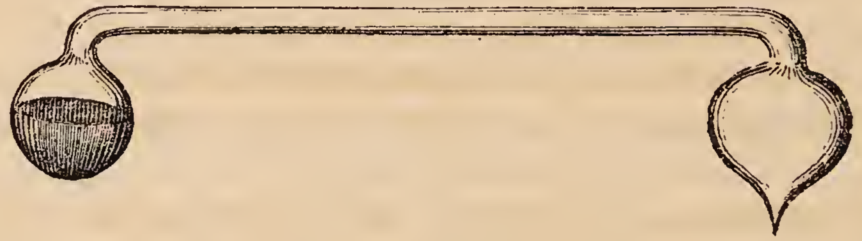
54. We have already stated that, when the air is still, the vapour, as it forms, accumulates on the surface of the liquid, and prevents further evaporation. Accordingly, to remedy this, a number of revolving fans are made to fly over the liquid surface, in some places, such as brewhouses, where the coolers are large, shallow vessels, formed in the upper story of the building, and open on all sides to the air;—so that, as the vapour is formed, it is wafted away and the liquor is soon cooled.

55. The danger of wearing damp clothes arises from the cold produced by evaporation. In the animal economy, heat is generated in the system and given out by the body. If, by any means, this heat be abstracted faster than a new supply is

formed by the process of respiration, the sensation of cold is produced; whereas, on the other hand, if the heat be not removed, exactly in proportion as it is formed, a feverish sensation is experienced. The first of these two effects is produced by the evaporation arising from damp clothes; and the general result to the person so affected is what we term *a cold.*

56. There is an instrument devised by Dr. Wollaston called the *cryophorus*, or cold-producer*, which strikingly shows the effect of cold by evaporation. This instrument consists of

Fig. 1.



A B

two bulbs, united by a stem. The bulb A, fig. 1, contains water, which is boiled in the bulb. The steam issuing from an aperture at B, expels all the air from within; and while the steam is so issuing, the bulb is sealed at B. When the whole is cool, water and vapour of water are alone contained within the instrument. If the bulb B, be placed in a freezing mixture, the vapour contained in that bulb will be condensed into water,—by which a partial vacuum is formed. The water in A is thus permitted to evaporate to such an extent, as to fill this vacated space. Another portion of vapour is condensed in B:—and thus the process is continued by converting part of the water in A into vapour, and condensing that vapour again into water at B. But every time that a portion of water is converted into vapour, a portion of heat is abstracted from the remaining water in A, until its temperature is so far reduced, that it is converted into ice. The writer has frequently shown this experiment during a hot day in summer.

57. Here we conclude this part of our subject; and, as we have dealt somewhat largely in detail and example, it may be useful to recapitulate the chief circumstances, which influence the process of evaporation:—

i. *Extent of Surface.* Evaporation, proceeding only from the surface must greatly depend, for its amount, upon the extent of surface exposed.

ii. *Temperature.* Fluids evaporate more quickly at high

* Compounded from the Greek κρύος *cold*, and φέρω to *produce.*

than at low temperatures, the rate of evaporation being proportional to the elasticity of the vapour generated.

iii. *State of the air*, as to dryness or moisture. As vapour is always tending to saturate the air, evaporation must be rapid or slow, according as the air is dry or moist. When a fluid is covered with a stratum of dry air, evaporation is rapid, even though the temperature be low. On the contrary, when the liquid has a stratum of damp air resting on it, evaporation is slow, even though the temperature of the air be warm.

iv. Evaporation is slower in *still air*, than when a current of air is blowing over the surface of the liquid: because, in still air, the stratum immediately above the surface of the liquid soon becomes saturated, and thus prevents further evaporation; whereas, a current of air wafts away the vapour as soon as formed.

v. Evaporation is quicker *in vacuo* than under atmospheric pressure:—because, in the first case, the vapour encounters no resistance from the atmospheric pressure, and immediately saturates the vacant space above the surface of the liquid; whereas, under the pressure of the air, the point of saturation is attained slowly, in consequence of the resistance of 15lbs on every square inch of surface.

Section II.—On Hygrometrical Instruments.

Peace to the Artist, whose ingenious thought
Devised the weather-house, that useful toy!
Fearless of humid air and gathering rains,
Forth steps the man—an emblem of myself!
More delicate, his timorous mate retires.

58. Thus does the amiable Cowper refer to a toy, with which every one must have been familiar from his childhood. The toy represents a house, constructed with two doors, within one of which is placed the figure of a man; within the other that of a woman. These figures are fixed, each at the extreme end of a horizontal lever, moving upon a central vertical axis; a little on one side of which is attached a piece of cat-gut. Now, there belongs to cat-gut, and to fibrous substances generally, a property, which we shall presently explain, of contracting in length under the influence of moisture, and of stretching when the air is dry. Accordingly, the figures are so arranged that in damp weather the cat-gut, by its contraction, draws that end of the lever to which the lady is attached, into the house; while the other end which bears the man, is protruded.

On a similar plan the figure of a monk, wearing a cowl, is constructed. In dry weather the cowl rests upon his back and shoulders; but during rain the cowl covers the head and face of the figure.

59. Every one, who plays upon a stringed instrument of music, is familiar with the action of the weather upon the strings. A change from damp to dry weather so far lessens the tension of the strings, as to make their tones too flat;—whereas, the contrary change from dry to damp weather increases their tension so much as to cause them to snap; and we very much question whether

> The Harp, that once through Tara's halls
> The soul of Music shed,

did not tell "a tale" more of damp weather, than of the ruin of a noble house, in

> The chord, alone, that breaks at night.

60. The property of cords contracting their length by moisture became generally known, it is said, in the following extraordinary manner. The famous Egyptian obelisk, erected by order of Pope Sixtus V., consists of a single piece of red granite, originally brought from Heliopolis by the Emperor Caligula. It is 85 feet $2\frac{4}{5}$ inches high, and 9 feet square at the base; its present height, including the modern ornaments at the top, is 132 feet. This enormous column was thrown down during the decline of the Roman empire, and lay buried under heaps of rubbish for centuries. Sixtus V. decided to erect it in the middle of the square facing St. Peter's. This undertaking had been already contemplated by several popes, but had been relinquished on account of the difficulty of accomplishing it. The dangers and toil of erecting so large a mass of stone seem to have excited dread and astonishment, and two or three years elapsed in making the necessary preparations, before the work could be begun. The papal court consulted men of science in various parts of Europe, and plans were received at Rome from all parts from architects, engineers, and mathematicians. At length the plan of Domenico Fontana, one of the successors of Michael Angelo in the works of St. Peter's, was accepted. In a series of beautiful engravings, with descriptive letter-press by himself, he has left us an account of the means by which he effected the work, in the year 1586. The day, on which the obelisk was to be raised, was marked with great solemnity. High mass was celebrated at St. Peter's, and the architect and workmen received the benediction of the pope;

and a prayer was offered to Heaven to prosper them in their undertaking. The blast of a trumpet was the given signal, when engines were set in motion by an incredible number of men and horses; but not until fifty-two unsuccessful attempts had been made, was the huge block lifted from the earth and swung in air. We smile at the present day at what appears to us to be "much ado about nothing," since a handful of men with proper machinery could effect a greater work than this at a very trifling cost, whereas the erection of this stone is said to have cost 36,975 Roman crowns*. But as it was, Fontana was on the point of failing in his operation, just when the column was about to be placed on its pedestal. It was suspended in air, and as the ropes which held it had somewhat stretched, the base of the obelisk could not reach the summit of the pedestal, when a man in the crowd, cried out "*Wet the ropes!*" This advice was followed, and the column, as of itself, gradually rose to the required height, and was placed upright on the pedestal prepared for it. When this was done the surrounding multitude shouted aloud, the cannons roared from the castle of St. Angelo, and the church-bells began to ring all over the city.

61. It is a common experiment to suspend a rope 10 or 12 feet long, and to fix to its lower end a heavy weight resting on the ground; the rope, when wetted, will lift the weight from off the ground.

62. The rationale of all this is, that water, by introducing itself within the cord, causes its fibres to twist and to take an oblique direction; it therefore produces between them such a separation as causes the cord to thicken or swell, and consequently to shorten, by virtue of the capillary attraction existing between the water and the fibres of the rope.

Linen cloth, when wetted for the first time, shrinks from a similar cause:—the threads of which it is composed contracting in the two directions of their intersecting threads.

Paper expands by moisture, because its substance may be considered to consist of an assemblage of short, thin filaments disposed irregularly in all directions, and lengthens in the dimensions of its surface, in proportion as the water, by insinuating itself between the intervals of those filaments, acts, by placing them farther asunder, proceeding from the middle towards the edges.

63. It will be seen then from the description just given,

* If we take the value of a Roman Crown at 6*s.* 1$\frac{3}{8}$*d.* this number will amount to £11,349. 5*s.* 5*d*

that, provided a substance can be procured which regularly diminishes by moisture, and elongates by drought, such a substance may become a moving power to an index-hand in front of a dial-plate, and may thus detect, and enable the observer to record, the variations in moisture of the atmosphere. We shall have to describe several instruments of this nature presently:—we must, however, first point out the simple, delicate, and beautiful method adopted by Mr. Dalton, in order to detect vapour at low tensions.

64. When a liquid is converted into vapour, the laws, which regulate its expansion by heat and contraction by cold, are the same as those of gases generally; *i. e.*, they expand $\frac{1}{480}$th of their whole volume at 32° for every degree of Fahrenheit's Thermometer. So soon as a liquid is converted into vapour by heat, it will not be condensed again into a liquid, unless more heat be abstracted from it than was necessary in the first instance to produce its vaporous form. But, if the quantity of heat so abstracted exceed ever so little the original amount employed, a deposition of moisture will result from the partial condensation of the vapour. If, therefore, we expose a body to the atmosphere, whose temperature is lower than the atmosphere, it will first abstract heat from the vapour in contact with it, and lower its temperature, until such vapour arrives at that temperature, which it had when it passed from the liquid to the vaporous form. The body will then bring the vapour to its own temperature; and this vapour will be found condensed in the form of dew on the exterior of the vessel. This effect we often see, when a glass of cold spring-water is taken into a warm room in summer. The temperature indicated by cold water contained in a vessel, which just begins to condense the vapour on the outside, is called the *dew-point;* and to ascertain this correctly is of great importance in meteorological observations. If the cold body be at, or nearly at, the temperature at which the vapour was formed, then the commencement of the condensation will be just shown by a slight dullness, seen upon the surface of the cold body, produced by the condensation of a very small portion of vapour. If the air be saturated with vapour, a very slight reduction of temperature will produce the formation of dew: but, if the air be dry, a body must be several degrees colder than the air, before dew is formed; and as a general rule—the drier the air, the greater will be the difference between its temperature and the dew-point. On this principle attempts were first made to estimate the hygrometric state of the atmosphere, by the Florentine

academicians with little success. Their method was to fill a glass vessel of the shape of an inverted cone with ice; and they estimated the degrees of dryness and humidity by the frequency of the drops formed by the trickling down of the dew, deposited from the chilled air in contact with the sides of the glass. The first accurate mode was introduced by M. Le Roi, and since adopted with slight modifications by Dalton. Water, at a temperature below that of the atmosphere, is poured into a thin glass tumbler, and exposed to the air. If an immediate deposition of dew take place upon its surface, the water must be poured back into the vessel which originally contained it, and the glass wiped dry. The water must then be exposed to a higher temperature. The water is poured back into the glass again; and in this way it is exposed at increasing temperatures, until that temperature is attained, at which a deposition of moisture would just be made on its surface; and such that 1° higher would altogether prevent condensation of vapour. This temperature is assumed to be that, at which the vapour suspended in the air had passed from the liquid to the vaporous state; and the elasticity corresponding to this temperature can be found from the table of the elastic force of vapour at all temperatures, from which we have already extracted several instances. This experiment must be performed in the open country, or at least at an open window; for the results within doors would seldom be accurate. The water ought to be 10° or 15° below the temperature of the atmosphere. In summer, spring-water will be found to answer very well; but, in winter, the water must be cooled with ice, or a mixture of salt and snow. But, if ice or snow cannot be procured, a quantity of pounded crystals of sulphate of soda, or of carbonate of soda, may be employed to cool it.

65. The dew-point being ascertained, for example, to be 50°, and the temperature of the air being observed to be 60°, it follows, by reference to the table (12), that the tension of the vapour in the atmosphere, at the time of observation, is equal to 0·375 inch of mercury.

66. A thin glass tumbler, a thermometer, and some cold water is all that is necessary to the performance of this important observation; but a refinement on this simple apparatus has been made for the benefit of those, who think luxury a necessary accompaniment of scientific observations. For the glass tumbler there is substituted a small cup made of thin silver, nicely gilt on the outside, of the capacity of about half an ounce, and fitted in a rose-wood case lined with velvet, which

serves as a stand for the cup during an observation. The water is cooled by successively adding a few grains of a powder, made of equal parts of Nitrate of Potash and Muriate of Ammonia intimately mixed, and by stirring it up with the bulb of a small thermometer. A small drawer in the rose-wood case is furnished with the powder and the thermometer.

67. The employment, however, of a silver vessel was made in an ingenious manner by Dr. Anderson, who concluded that the resplendent surface of polished silver, was well fitted to show the slightest deposit of moisture upon it. Such a vessel was accordingly filled with water, cooled down several degrees below the point of deposition, and placed at a sufficient distance from one thermometer employed to indicate the temperature of the air, and from another which indicated the point of depression of the moistened bulb produced by evaporation. The experiments were generally performed in a large, octagonal apartment, 50 feet in diameter, and 30 feet high; and, in order that the slightest deposition of moisture might be perceptible, the vessel was observed at a distance of 15 feet with a telescope. By these means, when no sensible deposition appeared to the naked eye, however closely the surface was examined, the drops of moisture formed on the surface became so much magnified, as to be seen increasing gradually in size.

68. Dr. Anderson has computed that the mean quantity of water, existing in the vaporous state in a column of air whose base is a square inch and reaching to the summit of the atmosphere, may be reckoned at about four cubic inches; and, since the surface of the earth contains about 790,000 millions of millions of square inches, it gives, as the whole amount of moisture in the entire atmosphere, a quantity consisting of rather more than 3 followed by 18 ciphers of cubic inches; which is about 11,794 cubic miles of water.

69. Mr. Dalton found, by exposing to the air a vessel of water at various low temperatures, and noting the rates of evaporation, that they were exactly equal to the difference between the tension of the vapour which would saturate the atmosphere at the temperature of the water, and the tension of the vapour actually suspended therein.

We now proceed to a description of some of the various hygrometers, that have been contrived, from time to time, by various philosophers.

70. All hygrometers may be said to depend upon three principles. Those of the first kind, may be referred to the property possessed by some substances of expanding by mois-

ture, in consequence of its penetrating their substance; while in dry air the moisture is given out, and these substances contract in bulk. Such bodies, by swelling out in breadth owing to moisture, necessarily contract in length; and the original length is re-attained by the shrinking of the breadth at the departure of the moisture. Almost all bodies abstract moisture from the air, but in different proportions. A piece of glass, or metal, weighs less when carefully dried, than after exposure to a humid air; and a sheet of paper, carefully dried and weighed, will, after having been kept in a drawer for several days, be found to be a few grains heavier than when warm and dry. Substances, that are soft and yielding, are best adapted to the construction of hygrometers. Such are the organic substances, as wood, a beard of corn, whalebone, hair, and animal membranes.

71. The second kind of hygrometers depends upon rapidity of evaporation; and the third kind upon the beautiful principle, which we have already discussed, viz., the condensation of vapour by a body colder than the atmosphere. We proceed to a description of a few specimens of the three varieties of instruments.

72. First Class. The following is a hygrometer of a very simple construction. To a nail or hook, fastened in a wall, let the end of a piece of whipcord or cat-gut be attached, and let this pass successively over four or five pulleys, whose axes are fixed in the same wall. At the other end of the cat-gut hangs a weight, for the purpose of giving the cord a proper degree of tension, having an index fitted to it; and opposite the point of this index, there is a graduated plate, made of metal, and fixed also against the wall. In very wet weather the string will, by its shrinking, draw the weight upwards, so that the index will point to some division near the top of the scale; against this division may therefore be written the words *very wet*. In very dry weather, the length of the string will be increased, and the weight will descend: the index will then point to one of the lower divisions of the scale; against which may be written the words *very dry*. The intervals between those two extremes may be divided into as many degrees as may be thought necessary; and words, indicative of the various degrees of moisture, written at the side.

73. Another simple construction of the hygrometer is the following. A cord or piece of cat-gut is fastened by one end to a hook, at the same time suspending a weight at the other end, and carrying an index round a graduated circle described on a

horizontal board, or table. Now, as we have already said that a cord or cat-gut twists by moisture and untwists as it dries, it is evident that an increase or decrease of moisture in the atmosphere will move the index, so as to show the amount of twisting or untwisting, and consequently the increase or decrease of moisture.

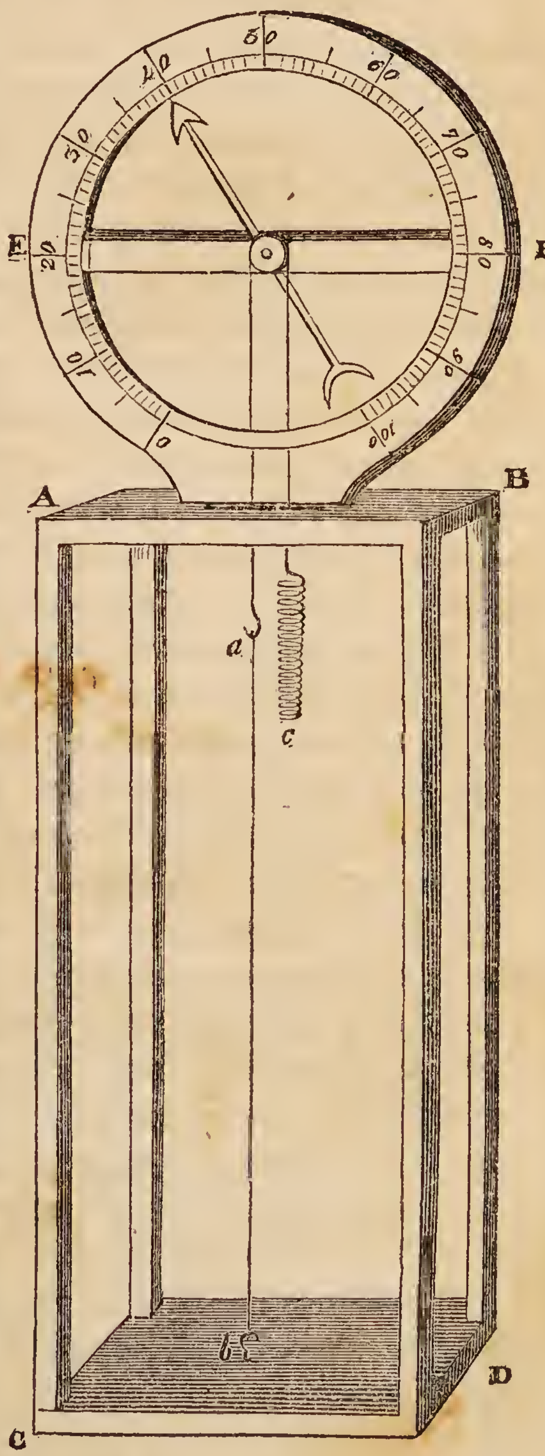
74. The cat-gut Hygrometer, proposed by Molyneux in 1685, is of the following form, as constructed by Coventry. The cat-gut, which may be of any convenient length, is suspended from a bracket, and stretched by a weight at the lower extremity. Near the bottom is a circular card of pasteboard, attached to a round piece of cork, through which the cord passes. The circumference of the card is graduated into 100 equal parts. Another card connected with the catgut in a similar manner, and intended to record the revolutions of the other, is placed at one-tenth of the length of the cord from the fixed point, and divided into ten equal parts. There is a vertical line along the frame which supports the cat-gut, which line serves to point out the indications of the circular card. In adjusting the instrument to extreme moisture, the cord is completely moistened with water, and when it ceases to untwist, both the circular cards are turned round till the zero upon each points to the vertical line. It is more difficult to obtain another fixed point, and indeed this is not necessary; since the instrument though tolerably delicate, can scarcely be employed except to point out general differences with respect to moisture.

75. Dr. Hooke's Hygrometer consists of the beard of a wild oat, connected with an index in the following manner. There is a brass plate about four inches square with a ring or circle fixed to it, and graduated on the flat surface and on the inner edge. There is also a very light index of brass or steel, with a small, cylindrical clamp in its centre, into which is fastened the top of the beard of the wild oat, by a little peg; and the other end of the beard is fixed into another clamp about an inch under the plate, which having a little hole under the centre allows the beard to come through, in order to carry the index, and yet keep it in its place without preventing its torsion. There are also two wires coming down under the middle of the plate, which hold a small cross bar forming a small frame to carry the clamp that holds the bottom of the beard exposed to the air. The four feet, which support this instrument, must be about $1\frac{1}{4}$ inch long, to keep the frame under the plate from touching any thing upon which the instrument rests.

76. Many years ago Mr. Edgeworth constructed a wooden

automaton hygrometer. Its back consisted of pieces of soft fir-wood, about an inch square and four feet long. The pieces were cut contrary to the direction of the fibres of the wood, and were glued together: it had two feet before and two behind, all which supported the back horizontally; but were placed with their extremities, which were armed with sharp, iron points, bending backwards. In moist weather the back lengthened, and the two fore feet were pushed forwards; in dry weather the hinder feet were drawn up, since the obliquity at which the iron points were placed prevented it from going backwards. In a month or two this hygrometer walked across the room in which it was placed.

Fig. 2.



77. De Luc's whalebone Hygrometer is shown in fig. 2. There are many forms of this instrument, of which the following is the description of one. A B C D is a frame work; to the upper part of which is attached a graduated circle E F. The whalebone is usually about ten inches in length, and fastened at *a* and *b*. The spiral wire *c* is a counterpoise to the action of the whalebone. The point of extreme moisture (100) is that obtained by immersing the whalebone completely in water; whereas extreme dryness (0) is that indication of the index, when the whalebone is kept under a receiver in the presence of quick lime for three weeks, by which its maximum contraction is ensured. Medium degrees of moisture are indicated by medium points on the circle, as marked by the index.

De Luc says, that a slip of whalebone a foot long and a line, or $\frac{1}{12}$th of an inch, in breadth, weighing only $\frac{1}{4}$ grain, will support 166 grains.

78. There is another mode of constructing a hygrometer, or we should rather call it a hygroscope*; since most of these which we here describe, are more to be depended on for *indicating* moisture, than for *measuring* its amount. The one, to which we now allude, is formed of a rat's bladder filled with mercury, and tied to the end of a capillary tube. Any change in the moisture of the air will change the dimensions of the bag, and consequently cause the mercury to rise or fall in the tube. The two extremes of the scale attached are points of absolute dryness and humidity. This instrument is also liable to fallacy; since changes of temperature must always affect the height of the mercury in the tube.

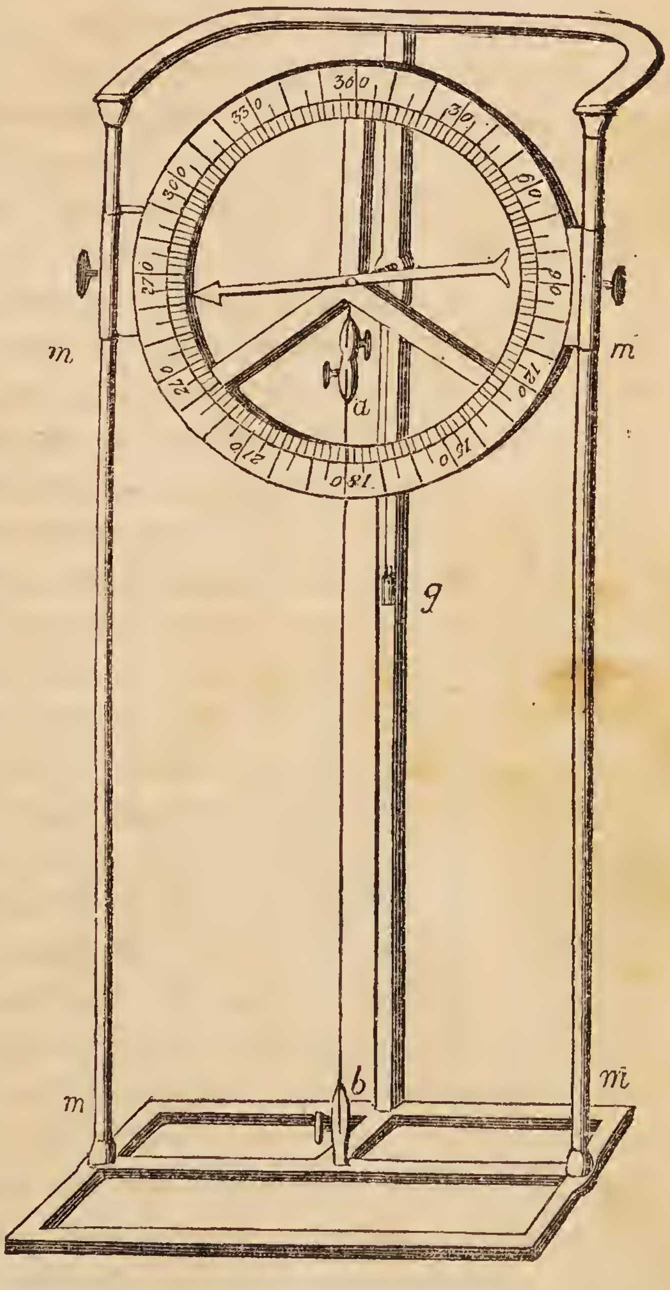
79. Leslie's ivory Hygroscope is a similar arrangement to the last. A piece of fine, grained ivory, about an inch and a quarter in length, is turned into the form of an elongated spheroid, having its shell as thin as possible, weighing only eight or ten grains, but capable of containing, at its greatest expansion, about 300 grains of mercury; and the upper end, which is adapted to the body of the instrument by means of a delicate screw, has a slender tube inserted, six or eight inches long, and with a bore of nearly the fifteenth part of an inch in diameter. The instrument being now fitted together, its elliptical shell is to be dipped into distilled water, or lapped round with a wet bit of linen, and after a considerable interval of time filled with mercury to some convenient point near the bottom of the tube, where is fixed the beginning of the scale. The divisions themselves are ascertained by dividing the tube into spaces, which correspond, each of them, to the $\frac{1}{1000}$th part of the entire cavity, and are equal to the measure of about three-tenths of a grain of mercury. The ordinary range of the scale includes about seventy of these divisions. To the upper end of the tube is adapted a small ivory cap, which allows the penetration of air, but prevents the escape of the mercury, and thereby renders the instrument tolerably portable.

As the atmosphere becomes drier, it attracts a portion of moisture from the ivory shell, which, suffering a contraction thereby, presses the mercury contained in it up into the tube. But, if the air become more moist, the shell imbibes moisture, swells, and affords a larger space for the mercury; which therefore sinks in the tube: the scale is thus graduated according to the observed law of expansion and contraction. This instrument also is likely to lead to fallacy from changes in temperature.

* The Greek word σκοπεω signifies to *perceive.*

80. Saussure constructed a hygrometer, which he thought to be free from the irregularity of the action of cords and catgut. The action of his instrument depended on the longitudinal expansion of a human hair; and it is probably more delicate than any hygrometrical instrument we have yet described. The general appearance of this instrument is similar to the whalebone hygrometer of De Luc. The hair is freed from all unctuosity by being boiled in ley. The hair, *a b*, fig. 3, is kept in a state of equable distention, by means of a small weight of three or four grains (*g*) which is suspended from the opposite side of the axis of the index, and thus stretches the hair without breaking it. The hair is fastened by two nippers at *a* and *b*;—and the dial-plate can be raised or lowered upon the uprights (*m m m m*) by slides, so as to be accommodated to the length of the hair. Saussure determined the point of extreme dryness by placing the instrument under a receiver in the presence of dry caustic alkali, or some other powerful desiccant; where it was allowed to remain, until the hair had acquired its maximum contraction breadthwise, and consequently its minimum of length. The point of extreme dryness being thus fixed, gives a point which may be considered regular and uniform. He then introduced into the receiver several small known quantities of water. This was done by wetting small pieces of linen and weighing them accurately; and thus the quantity of liquid introduced was known. He then withdrew

Fig. 3.



them, and re-weighed them; by which means the quantity of liquid evaporated each time was determined. This experiment being often repeated at a constant temperature, it was found that, whatever variation the hygrometer had previously undergone, it returned to the same point, when the quantities of vapour in the receiver were equal. The same result was obtained at different temperatures: the indications at the same temperature being always the same; but the absorbed quantity of water necessary to be vaporised in the same space, in order to move the index-hand of the hygrometer through the same number of degrees, varied with the temperature. It was necessary, therefore, to observe the indications of the thermometer, as well as of the hygrometer, in order to obtain the actual quantity of water suspended in the form of vapour; and these two observations are sufficient for obtaining accurate results. The principal advantages of Saussure's hygrometer are derived—first, from the unchangeable nature of the material of which it is formed, by means of which it retains its hygroscopic power longer than any other organic substance; second, from the extreme tenuity of the substance itself, which enables it to assume, very quickly, the state of the surrounding medium; and third, from the small effect which, in consequence of this tenuity, it produces on the hygroscopic state of the medium to which it is exposed.

81. We may here mention Captain Kater's hygrometer, the action of which depends upon the torsion which changes of humidity produce in the naturally twisted beard of grass, known in the Canarese language by the name of *Oobeena Hooloo.* This is the *Andropogon contortum** of Linnæus, and is gathered in Mysore in the month of January. The frame of Captain Kater's instrument is commonly cylindrical; and, in order that it may allow the air to pass through it freely, it is formed of small bars of brass, or of silver. Upon one end of this frame is soldered a flat plate, having a projecting rim to protect the index, which turns upon it, over a circular dial divided into a hundred equal parts. The index, which is very slender, and nicely balanced, is put on one end of an axis of silver wire, which has liberty both to turn round and to shift a little longitudinally through double conical holes in the frame. The axis extends about half the length of the frame; and a part of it next the index, is formed into a screw of fourteen or fifteen threads. This is effected by twisting lightly round it a small

* *A man's beard twisted.* The former word is derived from the Greek ἀνὴρ a *man*, and πώγων a *beard.*

silver wire. A loop and drop, made of fine gold wire, are so formed, that, when suspended from the axis, the loop may slide freely along the screw; and by the number of threads thus run over, it can show the number of complete revolutions of the index. The farther end of the axis is swelled a little, and has a notch to receive the end of the grass-beard, which is fixed by drawing upon it a sliding ring. This beard is then extended in the line of the continuation of the axis, till it meets the frame where its other end is fixed similarly to the former one, but admits of adjustment by a screw which stretches it slightly.

Such is a brief outline of the very simple and ingenious mechanism, by which the gradual expansion and contraction of the hygrometric substance communicates a rotatory motion to the index; so that, while the index shows the fraction of a revolution on the graduated dial, the loop and drop indicate the number of complete revolutions, or the integral number of hundreds of degrees, which the index has passed over on the dial. So great is the sensibility of this instrument, that its index makes ten or twelve revolutions while that of Saussure makes but one.

82. Since, by the absorption of moisture a body becomes heavier, substances such as *sponge* have been fixed at the end of a lever. The sponge is first washed thoroughly in water; and, when dry, washed again in vinegar containing muriate of ammonia, or carbonate of potassa; after which it is dried again. It is then fixed to the end of the beam of a balance. If the air become moist, the sponge will absorb the moisture, and its weight will increase, and consequently will preponderate, and turn the index of the beam towards that side; but, on the contrary, when the air becomes drier, the sponge becomes lighter, and the index turns towards the opposite side; thus showing the hygroscopic state of the atmosphere.

83. Mr. Gould, in the *Philosophical Transactions*, recommends sulphuric acid instead of a sponge, on account of its absorbent property for water. The alteration in this liquid is so great, that three drachms have been known to become nine, by fifty-seven days' exposure to the atmosphere. In this way a pair of scales may be made a hygroscope; one of the pans containing the sulphuric acid: but, as the acid merely absorbs moisture, and does not give out any, its action is limited; and besides this, the acid must be frequently changed, and its specific gravity known in the first instance; and even then, its absorbent power is greater at the beginning, when the acid is strong, than when it contains much water.

In the case of the sponge, the arrangement of the index and graduated arc may be varied by making the arm, which bears the counterpoise, itself perform the part of an index, by passing near a graduated arc. That arm may be longer than the one which bears the sponge; by which means a greater leverage is obtained, and a greater indicating power.

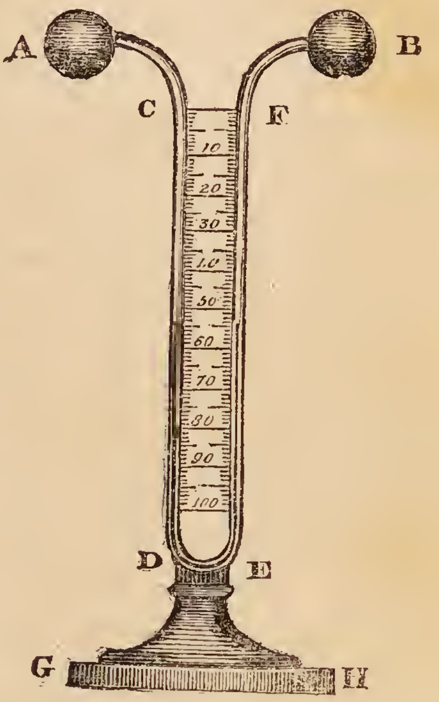
84. Drs. Desaguliers and Hales contrived another form of the Sponge-Hygroscope. A horizontal axis is constructed, having a small part of its length cylindrical, and the remainder tapering conically, with a spiral thread cut in it, after the manner of the fusee of a watch. The sponge is suspended by a fine, silk thread, to the cylindrical part of the axis, upon which it winds. This is balanced by a small weight, suspended also by a thread, which winds upon the spiral fusee. When the sponge grows heavier in moist weather, it descends, and turns the axis, and so draws up the weight; which coming to a thicker part of the axis, becomes a balance to the sponge, and its motion is shown by an attached scale, and *vice versâ* when the air becomes drier.

85. Second Class. Having thus described various Hygroscopic Instruments formed of organic substances, we proceed to a description of one or two of those instruments, which depend for their action upon the varying rates of evaporation. By far the most numerous class is that which we have just left; and all such are more or less objectionable, on account of the partial decomposition, which exposure to air and moisture continually induces on the organic substances entering into their construction; and although some of them are composed of materials, which resist the action of the weather better than others, none of them can be said to be indestructible, and all of them in the course of time lose, in a great degree, their hygroscopic properties. Their scales, therefore, however accurately constructed at first, are subject to a gradual derangement, and require occasional adjustment to render their indications at all correct. This is a great objection to the use of such instruments; but it is an objection, from which the hygrometer, which we will now describe, made by Sir John Leslie, is entirely free.

86. The instrument, which is nothing more than the differential thermometer of Leslie, under a slightly different form, consists of two glass bulbs, A and B, fig. 4, connected with each other by a bent tube, C D E F, which is fixed to the stand G H, and contains a small portion of sulphuric acid, tinged with carmine, to render it more distinctly visible. When the bulbs, both of which are filled with air, are at the same

temperature, the liquor in the recurved tube remains stationary; but, if one of the balls, as A, be colder than the other, B, the air in the latter, by its greater elasticity, immediately depresses the liquor in the limb F E, and raises it in an equal degree in the limb C D. One of the balls is accordingly covered with a coating of cambric, or tissue-paper, and kept continually moist with pure water, conveyed to it by filaments of floss silk, from an adjoining vessel. The evaporation of the water quickly cools the surface of the ball, in a degree proportioned to the rapidity with which the process is carried on, which will depend partly upon the temperature, and partly upon the dryness of the air around; and hence the depression of the liquor in the limb F E becomes an indicator of the relative dryness of the surrounding air. The caloric abstracted from the moistened ball, by evaporation, is incessantly supplied by the air, and the contiguous bodies; and in the course of two minutes, the maximum of effect is produced. Were it not for this continual influx of temperature, no limits could be assigned to the degree of cold that might be induced.

Fig. 4.



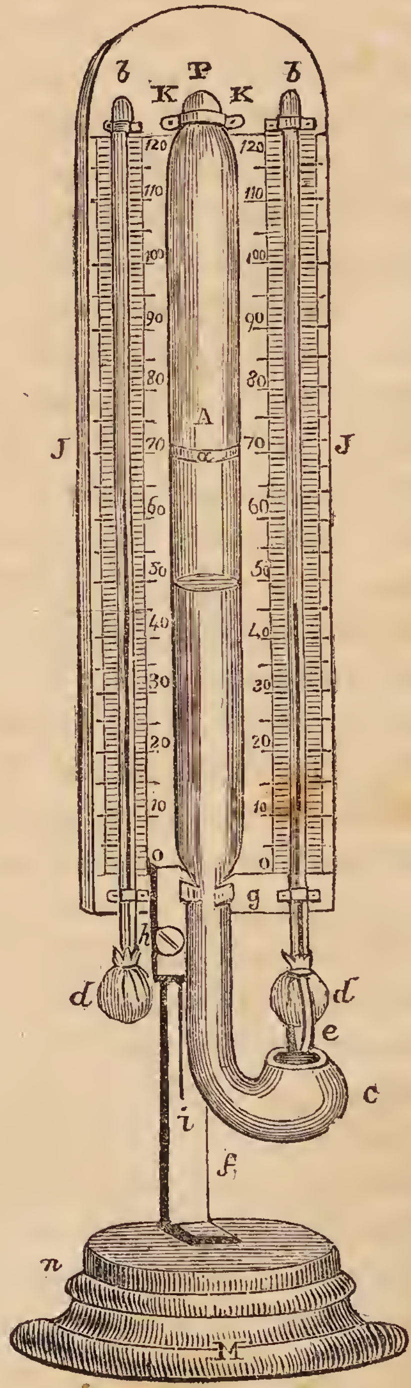
The scale of this hygrometer is formed by dividing the interval between the boiling and freezing-points, into 1000 equal parts; so that 10° correspond to 1° of the centigrade-thermometer, and 50° to 9° of Fahrenheit. This hygrometer acts equally well, when the moisture on the balls is in a frozen state: but the heat required for the melting of ice being about a seventh part of what is necessary for the conversion of water into vapour, the temperature of the coated ball will, in like circumstances of the air with regard to moisture, sink a seventh part more than before; and therefore, the degrees indicated by the instrument must, in that case, be reduced 1° in 7°, to adapt the scale to the actual state of things.

When the instrument is intended to be portable, Leslie recommended the following adjustment. The two balls are placed in the same perpendicular line, one above the other, and are protected from injury by a case of wood or ivory; so that the instrument may thus be carried about with perfect safety. An ordinary thermometer, having its bulb covered with moistened

paper, gives the same indications as this little instrument, if its temperature be subtracted from the temperature of the air, determined by a naked thermometer, placed in similar circumstances with the other.

87. Dr. Mason constructed a hygrometer, which is valuable, if its indications may be depended upon; since it possesses certainly, the advantage of great simplicity. He considers that Leslie's hygrometer, by evaporation, offers erroneous results; it being influenced by radiation and currents of air, and much calculation being required, before the absolute quantity of humidity can be ascertained.

Fig. 5.



The instrument, as represented in fig. 5, may be thus described. Upon the margin of a stand M, is fixed an upright rod of brass *f*, supporting, by a semi-circular clyp at *a*, the scale J J; in the middle of which a space is left, to receive a glass tube A, formed on the principle of the bird-fountain, having on each side of it a thermometer, *b b′*, both ranging from 0° to 120° Fahrenheit, and firmly attached to the scale already described. The bulbs, *d d*, of these thermometers are covered with white Persian silk; but round the stem of one, a thread of floss silk *e*, is attached, which terminates in the cup of the fountain *c*. This fountain can be removed by turning the screw *h*, which allows the support *g*, to move in the groove *i*, bringing the support *g*, to the contracted part of the fountain. The upper part of the fountain which is fixed by the double clyp K K, is hermetically sealed at P; the size of the orifice in the cup *c*, which is oval, is $\frac{1}{4}$ of an inch in length, by $\frac{1}{8}$ in breadth.

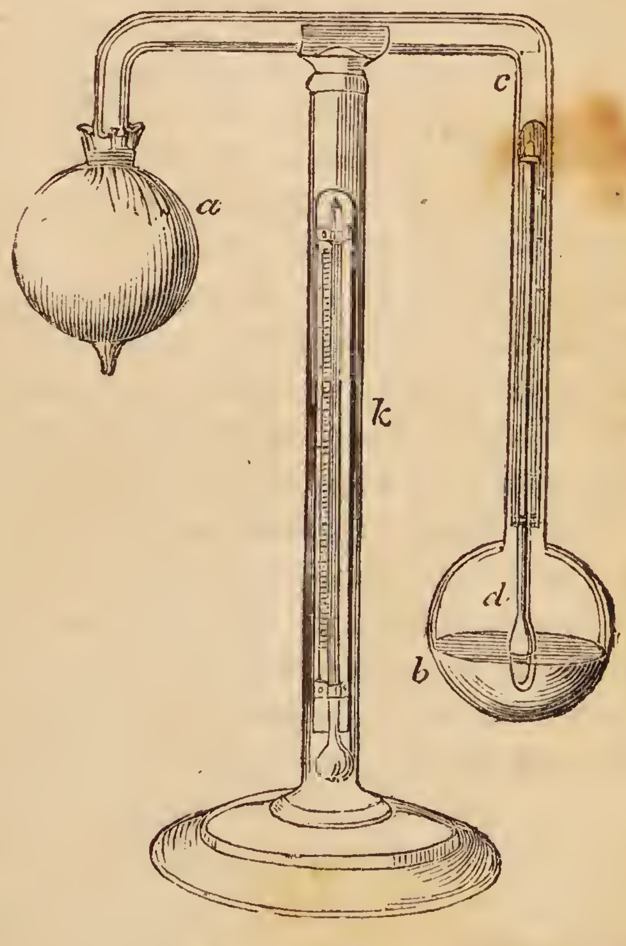
It will be seen, from this description, that the bulb of one of the thermometers, being connected with a reservoir of water, is kept wet by capillary attraction; and, as evaporation is con-

stantly taking place, its temperature is reduced below that of the other bulb. Now the difference between the temperatures of the two thermometers, marks the number of degrees of the hygrometer; thus, suppose the temperature indicated by the dry thermometer, be 75°, and that of the wet one 68°, then 7° of dryness are indicated. There are certain tables accompanying the instrument constructed by Dr. Mason, for correcting the indications of the instrument, when under the influence of wind. Both thermometers are covered with silk; the one (as we have seen) for the purpose of absorbing water, and the other to prevent the effects of radiant and reflected light and heat.

The zero of Dr. Mason's hygrometer is, when both the wet and dry thermometers indicate the same temperature; and then he assumes that the atmosphere is completely saturated with moisture.

88. Third Class. In our *third* division of hygrometers, that of Professor Daniell is the most important. This elegant instrument is represented in fig. 6. It consists of a cryophorus (56) containing ether instead of water. The two thin glass bulbs of the cryophorus, *a* and *b*, are connected by a tube, whose bore is about one-eighth of an inch. The bulbs are $1\frac{1}{4}$ inch in diameter, and the tube is bent at right angles over the two bulbs. The arm *b c* contains a small thermometer *d* whose bulb is elongated, and descends into the bulb *b*. This bulb *b*, having been filled about two-thirds with ether, is heated over a lamp, till the liquid boils, and the vapour issues from the capillary tube *f*, on the under side of the higher bulb *a*. The vapour having expelled the air from both bulbs, the capillary tube *f*, is permanently closed. The bulb *a* is then covered with a piece of muslin. The stand *g h* is of brass; and the trans-

Fig. 6.



verse socket i is made to hold the glass tube in the manner of a spring, allowing it to be moved or fixed with ease. A small thermometer k is also inserted into the pillar of the stand.

The manner of using the instrument may be thus described. After having driven all the ether into the lower bulb b, by the heat of the hand applied to the upper bulb, or by inclining the tube, the instrument is to be placed at an open window, or out of doors, with the bulb b so situated, as that the surface of the liquid may be upon a level with the eye of the observer. A little ether is then to be dropped upon the covered bulb. Evaporation immediately takes place, which, by abstracting heat, cools the bulb a, and causes a rapid and continual condensation of the ethereal vapour within it, together with a diminution of pressure. The consequent evaporation from the included ether produces a depression of temperature in the bulb b, the degree of which is measured by the thermometer d. This action is almost instantaneous; and the thermometer begins to fall in two seconds after the ether has been dropped on the bulb a. A depression of 30° or 40° is easily produced; and ether may be sometimes seen to boil when the thermometer is below the zero of Fahrenheit. So soon as the bulb b is cooled by this artificial process down to the dew point of the surrounding air, a condensation of the atmospheric moisture takes place upon its surface, and this first makes its appearance in a narrow ring of dew on a level with the surface of the ether. The temperature at which this occurs, viz., the *dew point*, is to be carefully noted. It is advisable, when the bulb b of the instrument has been made of transparent glass, to have some dark object behind it to indicate the first deposition of dew more correctly; but, according to the last improvement of Mr. Daniell, this bulb is formed of black glass. The depression of temperature is first produced at the surface of the liquid, where evaporation takes place; and the currents, which immediately succeed to effect an equilibrium, are very apparent. In damp or windy weather, the ether should be very slowly dropped upon the bulb a; otherwise, the descent of the thermometer will be so rapid, as to render it extremely difficult to be certain of the degree at which deposition commences. But, in dry weather, the bulb requires to be well wetted more than once, to produce a sufficient cold.

This instrument has, on some occasions, been applied to experiment on gases and vapours enclosed in a receiver. A hole is perforated in the side of the receiver, through which the tube, proceeding from the bulb containing the thermometer, is first passed, and then welded by means of a lamp to the tube attached

to the other bulb outside the receiver. The stem is secured in the hole of the receiver with cement, the ether is boiled, and the capillary tube closed as before. Muslin and ether being applied to the outer bulb, as before, the hygrometric phenomena proceed on the inside. With this arrangement, Mr. Daniell confirmed the view of Dalton and De Luc; that the quantity of moisture, which can exist in a given volume, depends solely upon the temperature, and is not influenced by the pressure or density of air or other elastic fluids.

89. When this instrument is required to act as a weather-glass, to predict the greater or less probability of rain, &c., it is only necessary to know the difference between the constituent temperature of the vapour and that of the air. The probability of rain, or of other precipitation of moisture from the atmosphere, is in an inverse proportion to this difference.

By combining barometrical observations with the indications of this hygrometer, the observer becomes "*weather-wise*," in the perfectly legitimate sense of the term. In summer, when the diurnal variations of temperature are great, regard must be had to the time of day when this hygrometer is used. In the morning, if the difference be small betweeen the temperature of the air and the constituent temperature of the vapour, it must, not be forgotten that the accession of heat during the day is great, and that the difference will probably increase.

If the dew-point should at the same time be lowered, it is an indication of fine weather. But, if the heat of both should increase with the day in nearly equal progression, rain is almost certain to follow; since the heat of the air greatly diminishes with the setting sun. In showery weather, the indications of this hygrometer vary rapidly 3° or 4°; and a person, making observations at short intervals of time, may easily predict the approach of a storm.

Fogs and mists produce the same effect upon this instrument as the precipitation of rain. A change from fine weather to rain, is more quickly perceptible in low situations, than a change from wet to fine weather; the reason is, that the effect of a shower lasts rather longer than the state of the atmosphere in higher situations would allow, on account of the exhalations from the moistened ground.

In cases of mist, fog, and cloud, this hygrometer will sometimes afford opposite results to those usually exhibited. If it be brought from an atmosphere of a higher temperature into one of a lower degree, in which condensed aqueous particles are floating, the moisture will begin to be deposited upon the black

bulb, at a temperature several degrees higher than that of the air. This difference is probably proportional to the density of the cloud or mist; but Mr. Daniell is not conclusive on this point.

We believe, both from authority and experience, that this instrument is more sensible and accurate than any we have yet described. Its use requires care and experience; but this remark applies equally to almost all scientific observations, where accurate results are wanted: if an approximation only to accuracy be all that is required, a less delicate instrument, and less careful observations, will suffice.

90. Mr. Thomas Jones has contrived a hygrometer on the same principle as that of Professor Daniell; but simpler in construction and less costly. Mr. Jones's instrument consists of a mercurial thermometer and a graduated scale about $4\frac{1}{2}$ inches in length. At the lower part of this scale, the glass tube is bent to form a right angle, at the end of which the bulb of the thermometer rises parallel to the scale, and about an inch from it. The bulb is about one inch long, and cylindrical in form, with a convex top of black glass, which projects a little beyond the sides of the bulb. The bulb below the flattened surface is covered with black silk. The scale is attached to a wire three inches long, and turns upon a joint-screw passing into its edge; the other end of the wire is placed in a tubular foot fixed to the inside of one end of the case, so as to form a stand for the instrument. The case also contains a bottle of ether.

In order to use this instrument, the temperature of the air is first noted by the thermometer. Ether is then poured on the silk cover of the bulb, or the mouth of the bottle of ether is placed in contact with the upper part of the covered surface of the bulb, when, by gently inclining the bottle, the ether will flow down without melting the top of the bulb and the latter will soon become dull from the deposit of moisture on its surface, the temperature of this point (the *dew-point*), and then the difference between it and the first temperature, are thus ascertained.

91. Adie's Hygrometer. This consists of a thermometer, having a small bulb, enclosed in an exterior case or bulb of black glass, which is covered with silk, except a small space of about one quarter of an inch in diameter, whereon the deposit of moisture is to be observed. The space between the outer and inner bulbs is nearly filled with a liquid not likely to freeze by the depression of temperature, necessary for finding the dew-point. Alcohol, mercury, linseed-oil, &c., will do. When an

observation is to be made, ether is applied to the silk, and the instrument is to be kept in a state of gentle agitation, to render the inner and outer bulbs of one temperature.

92. In the Hygrometer of Pouillet, the stem of a thermometer descends through, is closely fitted into, and secured in, a perforation in the bottom of a small silver cup; the bulb only of the thermometer being left above, within the cup. When the instrument is to be used, ether is poured into the cup, till it covers the bulb; and the consequent evaporation causes a deposition of dew, in the form of a narrow ring, on the outside of the cup, and on a level with the surface of the ether.

93. In Dr. Cumming's Hygrometer, the dew-point is better ascertained by inclosing the bulb of a delicate thermometer, covered by a sponge, in a tube of polished tinned iron, silver, or platinum. The sponge is wetted with some evaporable fluid, such as ether, or alcohol, and a stream of air is blown through the tube, when a copious and rapid deposit of dew takes place on the surface of the metallic tube. This hygrometer is fitted up with a portable air-syringe, by which a current of air is projected through the metallic tube placed above it.

94. There are several important points connected with the presence of vapour not only in the atmosphere, but in all gaseous fluids, to which points we must now direct attention. The volumes of vapours and gases are greatly influenced by temperature, and barometric pressure; and the volumes of gases depend very much upon whether they are estimated in a dry, or moist, state. We shall therefore speak of the modes of correcting volumes of gases: firstly, for Temperature; secondly, for Atmospheric pressure; and, thirdly, for Aqueous vapour.

It is obvious, that, as atmospheric temperature and pressure are constantly varying, results obtained at one time cannot be compared with those offered at another time, unless under precisely similar circumstances of temperature and pressure,—to obtain which might perhaps be impossible. Recourse has therefore been had to a certain standard, to which all results can be referred; as in the case of obtaining specific gravities; in which we stated that pure water at 60° is the standard adopted. (Hydrometer, 27.)

95. The standard temperature and pressure in this country is fixed at 60° of Fahrenheit's scale, and 30 inches of the barometrical mercury. Hence, a gas obtained at any other temperature or pressure, can be reduced to the standard in the following manner.

96. Although we are in the habit of saying that gases and vapours of all kinds, when not in contact with liquids, increase in volume for every degree of Fahrenheit's scale $\frac{1}{480}$th part, yet it must not be understood that this increase in volume applies indifferently to any temperature. What is meant is that the increase is $\frac{1}{480}$th part of the volume at 32° of the same scale; and the decrease of every degree is in the same ratio. So that it is easy to calculate how much a volume of gas would increase, or diminish, in volume by a change of a certain number of degrees. At 54°, for example, the bulk of the gas does not increase $\frac{1}{480}$th part for one degree, but in the proportion found by adding to 480 the difference between 32° and 54°. So that at 54° a variation of 1° in temperature would produce a variation in bulk of the gas equal to $480+22$ or $\frac{1}{502}$ of the whole volume at 54°. This will be clear by taking 480 cubic inches of gas at 32°. At 33° they become 481 cubic inches;—at 34°, 482 cubic inches;—and so on, the increase being for 1° $\frac{1}{480}$th part of the volume at 32°.

97. The rule for correction for *temperature*, therefore, is to add to 480 the number of degrees above 32°, and to divide the observed volume by this sum, which gives the expansion, or contraction, for each degree at the observed temperature: then multiply this by the number of degrees between the observed temperature and the temperature to which the gas is to be corrected, and this will indicate the whole expansion or contraction: subtract this, if the observed be *above* the corrected temperature; or add it, if the former be *below* the latter.

For example:—Suppose 100 cubic inches of dry atmospheric air, at 65°, are to be corrected to mean temperature, or 60°. The difference between 65° and 32° is 33, which added to $480=513$; then 100 cubic inches divided by 513 gives 0·19493 of a cubic inch, the expansion for each degree; this, multiplied by 5, the difference between 65° and 60°, gives 0·97465 of a cubic inch, the whole expansion; which, subtracted from 100 cubic inches, gives 99·02535 cubic inches, the amount of volume of 100 cubic inches of air at 65°, when reduced to 60°.

Again; suppose 100 cubic inches of gas at 40° are to be corrected to mean temperature: then the expansion for every degree is obtained by adding 8° (the difference between 32° and 40°) to 480. This is equal to 488; and dividing 100 by this we get 0·20491 of a cubic inch as the expansion of each degree at 40°:—this multiplied by 20 (the difference between 40° and 60°) we get 4·0982 cubic inches, the whole expansion for the 20° between 40° and 60°. This being added to $100=104·0982$

cubic inches as the extent of the volume of gas corrected to the mean temperature of 60°.

98. Correction for *pressure* is a simple operation, and will be readily understood by reminding the reader, that, as the barometer column very faithfully represents the pressure of the atmospheric air, so, all gases procured during any state of the barometer, must be under exactly the same pressure as the surrounding air:—if the barometric column be low, the density of the air and other gases is small; and when the mercury is high, the reverse is the case. By observing then a volume of air, or gas, at a certain pressure (as indicated by the barometer), and comparing this pressure by a rule of proportion, with 30 inches (the mean height), and increasing or diminishing the observed volume inversely in the same proportion, we get the volume, which this air or gas would occupy—supposing the barometer stood at 30 inches.

Thus, suppose 100 cubic inches of gas have been obtained, when the barometer indicated 29·43 inches;—then, as 29·43 inches (the observed height of the barometer) is to 100 (the observed volume of gas), so is 30 inches (the mean height of the barometer) by inverse proportion to 98·1 cubic inches, which would be the volume of the gas at 30 inches of barometric pressure.

99. The third correction is for *aqueous vapour.* Gases, standing over water, soon become saturated with vapour; and as this quantity is always proportional to the temperature, the correction is easily made. A part of the observed volume, as also of its weight, is due of course to the vapour, which must be ascertained, before the proper weight of the gas can be obtained. Now it has been ascertained, that a cubic inch of permanent aqueous vapour, corrected to mean temperature, and pressure, weighs 0·1929 grains. In his excellent work on *Chemical Manipulation*, Dr. Faraday has given a table, exhibiting the proportion, by volume, of aqueous vapour existing in any gas standing over water, for every degree between 40° and 80°; barometer 30 inches. We select from this table a few examples—

40°	·00933	65°	·02190
45	·01133	70	·02566
50	·01333	75	·03020
55	·01586	80	·03533
60	·01866		

Now, suppose that 83 cubic inches of a gas standing over water had been weighed, and found to be 180 grains, at the temperature of 55° Fahrenheit:—Barometer 28·9. It will be

seen by the table above, that at 55° the portion of aqueous vapour in gas in contact with water, is ·01586, which, in the 83 cubic inches, will amount to 1·31638 cubic inches:—this, corrected to mean temperature, becomes 1·32946. The whole volume corrected to mean temperature and pressure becomes 80·75141 cubic inches; from which if 1·32946 cubic inches of aqueous vapour present be subtracted, we get 79·42195 cubic inches, as the volume of dry gas at mean temperature and pressure. Then 1·32946 cubic inches of aqueous vapour weigh ·25645 grains: this, subtracted from 180 grains, leaves 179·74355, the weight of 79·42195 cubic inches of dry gas.

100. The quantity of vapour, existing in the atmosphere, is, as we have seen, regulated by the elasticity of such vapour; and this elasticity is measured by the height, at which it is capable of supporting a column of mercury Now the elasticity of vapour at low temperatures, is small; and it often happens that, unless the particles be at a great distance from each other, they re-unite, and become again liquid. So that, at low temperatures, it is not always easy to estimate the quantity of vapour existing at any one time in the air; but the following rule is tolerably certain for all ordinary temperatures:—Ascertain, by the table of the force of vapour (12), the force of the vapour at the observed temperature. Let this number be made the numerator of a fraction, whose denomination is the constant number 30 (the mean height of the barometer). This fraction will denote the volume of vapour capable of existing in the atmosphere at the given temperature; supposing it reduced to the density of steam at 212°, or supposing its specific gravity $=0·625$. Thus, at 70° the force of vapour is 0·721: its volume, capable of existing in the atmosphere at that temperature, is, therefore, $\frac{0·721}{30}=\frac{721}{30000}$ or almost the $\frac{1}{42}$nd part.

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101. Here, we conclude our account of the Hygrometer, an instrument which, as a late accomplished philosopher well observed "is of the greatest utility, not only in meteorological observations, but in aiding domestic economy, in regulating many processes of art, and in directing the purchase and selection of various articles of produce. It will detect, for instance, the dampness of an apartment, and discover the condition of a magazine, of an hospital, or of a sick ward. Most warehouses require to be kept at a certain point of dryness, which is higher or lower according to the purposes, for which they are designed.

The printing of linen and cotton is carried on in very dry rooms; but the operations of spinning and weaving succeed best in air which rather inclines to dampness. The manufacturer is at present entirely guided by observing the effects produced by stoves; and hence the goods are often shrivelled, or otherwise injured, before he can discern any alteration in the state of the medium. Wool and corn have their weight augmented, sometimes as much as 10 or even 15 per cent. by the presence of moisture, &c." The hygrometer may also be employed in regulating the dryness of hot-houses, green-houses, &c. By its means the agriculturist may be more certainly guided in his observations of the barometer; which latter instrument is to be found in almost every farm-house. It is said also, that on board ship, when the hygrometer is used in conjunction with the marine-barometer, storms, whether of rain or of wind, can be predicted many hours in advance. Thus, if a fall of the mercurial column be accompanied by the indication of a relative degree of dryness of the hygrometer, wind alone is to be looked for; but, if the hygrometer indicate the presence of much moisture, rain, or rain with wind, may be expected to follow.

V.

THE VERNIER, OR NONIUS.

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1. In our article on the Barometer, we had occasion more than once to speak of the *Vernier*. Were the applicability of this ingenious contrivance limited to the barometer, we should have described it under the latter article; but, as it performs a very important part in the construction of many Philosophical Instruments, we devote a separate paper to its consideration, by which we shall have an opportunity of referring to other contrivances in some degree resembling the vernier.

2. That the use of the vernier is not confined to the barometer will be obvious, when we come to consider the way in which it is employed. It is a contrivance which is suited to all instruments adapted to the measurement of *length*, whether *curvilinear*, (such as the arc of a circle,) or *rectilinear;* and, as superficial and cubical measurements are but multiplied applications of linear measurement, the vernier has, of course, an extensive range of operation. The sliding-rule of the carpenter, the quadrant or sextant of the navigator, and the micrometer of the scientific astronomer, all receive an impress of value from this little instrument; indeed, there is no science that we can at present call to mind, wherein it is not necessary to measure length, breadth, and thickness; and this often with a degree of exactness so rigid, as to excite surprise in the minds of the uninitiated, and to elicit an inquiry as to how such minuteness can be attained, and, when attained, how we are sure that it is exact. The object, therefore, of the present article, is to answer these two questions; and we feel assured that a little attention on the part of the reader will have the effect of preventing the vernier from being in future the *un*employed *attaché* to several useful instruments, which it is now, in the hands of very many persons who are not scientific.

3. Before entering upon the subject of the *Vernier*, we propose to give a short account of the origin and nature of the weights and measures used in this country and in France:—at least, as much as is in any way connected with measures of length. This will be desirable; as, in order to know the true

value of a vernier destined to indicate small portions of an inch, it is necessary to know from what source the inch, foot, &c. have been derived.

4. In this country it is usual to refer all our measures of length to the *standard yard*, which has been determined by modern science with rigid exactness; indeed, so necessary is it to know the precise length of our yard, that some of the sciences, which are now among the beautiful and true, (beautiful because true,) owe their very lustre to the precision with which our instruments measure lengths and capacities of various kinds. In a rude state of society the standard measure of length was some natural object, and as such, it was liable to constant variation; thus the yard itself was a measure of the length of the arm of one of the early kings of England (it is said, of Henry the First, in 1101). Again, three grains of barley, placed end to end were taken as the measure of an inch, thirty-six of which went to the yard*. Now this seems to imply that the arm of a king ought to be just as long as 108 barley-corns; but, as we all know that neither kings' arms nor barley-corns are always of the same length, it is obvious that this method was not adapted to much precision. Advancing science called loudly for some unerring standard, for some rule, which would have all the rigour and truth of a principle, and which could be appealed to in after-ages; so that the accidents of fire, storm, or tumult, and the many casualties to which our lineal measures are subject, might not prevent posterity from deciding the real meaning of our distances, in the records either of history or of science.

5. In 1760 a brass standard measure of one yard, made by Bird, was deposited with the clerk of the House of Commons, and in so far it gave an uniformity to the length of the yard in this country, but still no general principle was known by which that yard could be replaced if lost; and it was not until 1824 that an undeviating rule was laid down, which, by being based upon scientific principles, became available for after ages, as well as for our own times. Its origin is briefly this. The science of Astronomy informs us that the length of the day and night taken together does not vary; we also know, that when a pendulum is made to vibrate, the time that it occupies in moving from side to side (which motion is called a vibration,) is due altogether to its length, and has nothing to do with the quantity or

* The origin of all English *weights* was a corn of sound ripe wheat, taken out of the middle of the ear, thirty-two of these well dried made up the old penny-weight. This number was some time after the reign of Henry VII. reduced to twenty-four.

quality of the matter of which the pendulum is formed. It follows, therefore, that all pendulums of the same length will perform the same number of beats or vibrations in the same time, with this especial proviso: that the observations shall be made at places having the same terrestrial latitude. This condition is rendered necessary by a change in the force of gravity, with every change of latitude. Centrifugal force is an antagonist power to gravitation, and is greater at the equator than at any other latitude, on account of the greater diurnal velocity of the surface of the earth at the equator: hence the force of gravity is diminished, and the number of pendulous oscillations in a given time likewise diminished; or, which amounts to the same thing, the length of a pendulum to vibrate in a given time must be reduced as we approach the equator. Thus, at London, (which is in latitude 51° 31′,) the length of the seconds' pendulum must be 39·1393 inches; while at Stockholm, in latitude 59° 20′, the length is 39·1654 inches. If, therefore, we note the respective number of beats in any one day of any number of pendulums of equal lengths, these numbers will all be found equal to each other, the latitude remaining the same; and if we suppose a pendulum of a given length to vibrate as many times as there are seconds in a day of twenty-four hours, (*i. e.* 86,400,) and if the length of such pendulum be called *a yard*, any mathematician or astronomer in after-ages could ascertain what is the length expressed by the term *yard* with the greatest degree of exactness, since all he would have to do would be to get the length of a pendulum vibrating 86,400 times in a day. The length of such a pendulum would not, however, be our yard; but, if its whole length be divided into 391,393 equal parts, 360,000 of such parts are taken as the *yard*; so that the pendulum vibrating seconds is longer than the yard by $\frac{31393}{391393}$ parts. This ratio between the lengths of the yard and the seconds' pendulum was ascertained by the late Captain Kater, a few years ago, and a bar of platinum was constructed by order of government, under the direction, we believe, of the same accurate observer, and deposited in the House of Commons under the name of the *Imperial Standard Yard.* This measure was destroyed in the disastrous fire, which consumed the two Houses of Parliament in 1834. The Astronomical Society has, however, supplied the deficiency. This valuable body has in its possession "a *Standard Yard* and a *Standard Scale*, as accurate as human senses, armed by the best means which science has hitherto contrived, can produce." (*Report of the R. A. S.*) Fac-similes of the Astronomical Society's Standard have been made for the

Danish and Russian governments, "so that there is no reasonable fear that the measure should be lost or vitiated."

6. In the above report it is remarked that "at first sight, scarcely any operation could be imagined more easy or more simple than that of making one straight line equal to another straight line; and it is only after a careful perusal of Mr. Baily's report, and a consideration of the accuracy which is demanded in such determinations, when employed in deducing the figure of the earth by the actual measurement of degrees, or in ascertaining the absolute length of the seconds' pendulum, that the difficulty of the task, or the importance of the result, can be appreciated."

7. The length therefore of the Astronomical Society's standard is exactly a yard; and all measures in common use may be compared with this as a standard, and corrected; and so long as this standard is carefully preserved, it will not be again necessary to have recourse to the pendulum.

8. Among the stormy clouds of the French revolution, there appeared a few shining spots, whose brightness has not yet passed away, which still beam upon deeds that have outlived the impulse which gave them birth, and which men of science will always appreciate and value, when the tumultuous Reign of Terror shall be remembered only in the neglected page of history. From among these boons to posterity we select two examples; first, the almost universal use of the decimal notation in arithmetical processes, when applied to the arts and sciences; and secondly, a highly philosophical standard of weights and measures. The extremely simple bonds by which all the modern French weights and measures are connected, we now proceed to show.

9. The systematical form of the spheroid, into which the earth is thrown by its diurnal rotation, renders the distance from the equator to the pole physically, and almost mathematically, equal in every longitude, and in either hemisphere. A meridional quadrant of the earth's circumference is therefore considered as a constant quantity; this is, in English terms, 6213 miles, 1450 yards, and is divided into 10,000,000 equal parts, called METRES, each of which is consequently equal to 39·370788 English inches. This mètre forms a nucleus, from which multiples and submultiples branch off, to express longer and shorter distances; thus, the *decamètre*, *hectomètre*, *kilomètre*, and the *myriomètre*, are respectively equal to 10, 100, 1000, and 10,000 metres; and the *decimètre*, *centimètre*, and *millimètre*, signify the 10th, the 100th, and the 1000th of a metre :—Greek

prefixes being employed for the augmented measures, and Latin prefixes for the aliquot parts. This is the standard for linear dimensions; but superficies is reckoned by the ARE, which is a square decamètre, of which each side is equal in English to very nearly equal to 32 feet 8 inches. From this proceeds a series similar to that before given, viz., the *miriare*, *kilare*, *hectare*, *decare*, *are*, *deciare*, and *centiare*; respectively equal to 10,000, 1000, 100, 10, 1, 01, and 001 ares.

From the decimètre cube is derived the unit of measures of capacity for liquid or dry substances, under the name of the LITRE, each side of which is equal to about four English inches square, and from this they have the *decalitre*, *hecatolitre*, *kilolitre*, and *myriolitre*; respectively equal to 10, 100, 1000, and 10,000 litres; and the *decilitre*, *centilitre*, and *millilitre*, severally equal to 0·1, 0·01, and 0·001 litres.

For some solid substances, such as fire-wood, the names of the units are different, but the principle is the same, the STERE and the *decistere* being, the former a mètre cube, and the latter the tenth of a mètre cube.

The last link in this connected chain is the standard of weight, which is derived from the mètre, thus:—The weight of a centimètre cube of distilled water is ascertained at the temperature of its greatest condensation, 4·1° cent. or 39·38°, Fahr., (Hydrometer, 16,) and is called a GRAMME. From this, seven others are derived, which, with it, form a decimal series, thus: *myriogramme*, *kilogramme*, *hecatogramme*, *decagramme*, *gramme*, *decigramme*, *centigramme*, and *milligramme*; being respectively equal to 10,000, 1000, 100, 10, 1, 01, 001, and 0001 grammes; the gramme being a cube of water whose side measures 0·3937 inches, (or rather more than one third of an inch,) in length*.

10. Thus we see, that if the English reader impress upon his mind the figures 3937, (which will be sufficient for ordinary purposes,) he will be enabled to translate French weights and measures into equivalent quantities expressed in English inches, by observing where to place the decimal point: for example,—

* The *Franc*, which is the French unit of money, is a silver coin containing $\frac{9}{10}$ths pure silver, and $\frac{1}{10}$th alloy, and weighs exactly 5 grammes. 5-franc pieces weigh 25 grammes, and are 37 millimètres in diameter. 27 of these, placed close to each other in a straight line, give the length of the *mètre*. The 40-franc gold piece weighs 12·9032 grammes. A kilogramme of pure gold is worth about 3441 francs, and of pure silver, 222 francs. The *decime* and the *centime* are, respectively, $\frac{1}{10}$th and $\frac{1}{100}$th of a franc.

		English inches.
Myriomètre	=	393700
Kilomètre	=	39370
Hecatomètre	=	3937
Decamètre	=	393.7
Mètre	=	39·37
Decimètre	=	3·937
Centimètre	=	0·3937
Millimètre	=	0·03937

And if we remember that the measures of *superficies*, *capacity*, *solidity*, and *weight*, are all derived, either from the mètre or from one of its aliquot parts, we shall see that the same four figures, 3937, will be an index available for the whole series of measurements.

11. It is much to be desired that English weights and measures were assimilated to those we have been describing; as there is now no general principle by which one species of measurement can be readily deduced from another. The custom of ages has, however, so bound up the received standards of weight and measure with the technical calculations of the artificer and of the retail-dealer, that any attempts at change, on a scale so extensive, would meet with obstacles almost insurmountable.

12. Having now thus briefly shown the principle on which the French weights and measures are computed, we will revert to the English inch in describing the *Vernier*, as it will bring more familiarly before the notice of the English reader the illustrations which we shall have occasion to adopt.

We shall, however, find it convenient to speak of the measurement of circular lines, or arcs, before we proceed with rectilinear measurement, because some of the more minute subdivisions were first applied to the former.

13. If we look at the curved edge of a quadrant, or of a semicircular protractor, or any similar instrument, we see that it is divided into degrees, the number of which is purely conventional. In this country, the circle is divided into 360 equal parts, called degrees; and for common purposes, that degree of minuteness is sufficient. For many of the more delicate operations, however, particularly in Astronomy, much greater minuteness is necessary. This minuteness is soon brought to a limit by the impossibility of the workman engraving the marks beyond a certain degree of closeness to each other, without confusing one with another. For example: a circle of six inches radius, if graduated into single degrees, would present a series of degrees, each about one-tenth of an inch distant from the other; if graduated to half-degrees, the lines would be one-

twentieth of an inch distant from each other, and so on: but the workman would soon arrive at such a minuteness, as he would not be able to surpass.

14. To increase the delicacy of the indications thus derived, Peter Nunnez, or Nonius, (as his name has been Latinised), devised a system of compound graduation. This individual was a Portuguese mathematician, born at Alcazar, in 1497. He was Professor of Mathematics in the University of Coimbra; and tutor to Don Henry, son of King Emmanuel of Portugal. In 1542, he published a treatise *De Crepusculis* (On Twilights), in which he described his mode of graduating a quadrant. He drew 45 concentric circles, or quarters of circles, round the quadrant. He then divided the outer quadrantal arc into 90 equal parts, the next into 89, the next in 88,—and so on through all the rest, until the innermost was divided into 46 only. By these means, in most observations, the plumb-line or index of the instrument would necessarily cross one or other of these circles, at, or very near, a point of division, whence, by calculation, the degrees and minutes of the arc might easily be obtained. For example, if the index crossed the eighteenth division of the arc which was divided into 74 parts, he stated the following proportion:—If a quadrant divided into 74 parts gives 18 divisions, how many would it give in a quadrant of 90 parts? Or

As 74 : 18 : : 90 : 21° 53′ 31″ which is the real angle required.

The correct graduation of these quadrants was so difficult, and their use so inconvenient, that the plan was never of much practical value.

15. Soon after that period, Jacob Curtius, Vice-Chancellor of the Germanic Empire, modified the graduation, as follows:—He described a number of concentric curves, the first of which extended to 91°, the second to 92°, the third to 93°, and so on; and then divided each of these arcs into 90 equal parts.

Clavius altered this method by describing 39 concentric arcs, the outer one being continued to 90°, the second to 91°, the third to 92°, &c., until the 39th extended to 128°. Each of these arcs he divided into 128 equal parts.

16. Curtius proposed a further variation, which consisted in setting off upon the first concentric arc within the outermost, the 60th part of such a portion of that arc as answered to 61°, and from that division continuing on, through the whole arc, the intervals of single degrees. By these means every division in this arc is advanced one minute of a degree more forward than the degrees of the first arc. At the beginning of the next arc, he took off the 60th part of 62°, and from that point continued

through the whole arc the intervals answering to single degrees; whereby each division in this arc is advanced two minutes beyond the degrees of the first. Thus he proceeded, till the degrees were divided into the whole number of minutes they contained.

17. All these arrangements, were, however, difficult to construct, and are with difficulty understood. This difficulty led to the adoption of a method of *diagonals*, by Richard Chauseler, in 1573. Those who possess a *plain scale* may have observed that, at one or both ends of the scale of inches, a series of lines are drawn nearly, but not quite, at right angles to the width of the scale. The use of those diagonal lines is to enable us to measure a quantity so small as $\frac{1}{100}$th of an inch, which is far too minute a quantity to be engraved in the common way. The manner in which this is accomplished, is as follows:—Suppose the scale to be 6 inches long; the first inch is divided, near both of the long edges of the scale, into 10 equal parts. If we call the respective divisions 0, 1, 2, 3, 4, &c., we shall understand what follows: A line is drawn from 0 on the upper edge to 1 on the lower edge, another line from 1 on the upper edge to 2 on the lower,—and other lines from 2, 3, 4, &c., respectively, to 3, 4, 5, &c., on the lower. By these means we obtain 10 diagonal lines. We then divide the width of the scale into 10 equal parts, and through the points of division, draw parallel lines, which are also parallel to the long edges of the instrument. These lines are numbered from 1 to 10; or, in most cases, the alternate lines only are numbered 2, 4, 6, &c. By this process, each diagonal line is divided into 10 equal parts, and as one end of any given diagonal is $\frac{8}{10}$th of an inch further from the remote end of the scale than is the other end of the same diagonal, it is obvious that the divisions of that diagonal enable us to break up $\frac{1}{10}$ of an inch into 10 equal parts, each of which must therefore be $\frac{1}{100}$th of an inch.

18. Suppose now that we wish to take 3·78 inches (or $3\frac{78}{100}$) from such a scale. We proceed as follows: place one leg of a pair of compasses on the line indicating 3 inches, and let the other leg fall on the 7th diagonal, by which we get 3·7 inches. But this quantity is not enough; we must add $\frac{8}{10}$ths of another diagonal, to obtain the true length; we therefore select the 8th division of the 7th diagonal, as the point where the second leg of the compasses is to fall. By these means we obtain 3·78 inches. In most scales, half an inch is divided into 10 equal parts; and from those parts, diagonals are drawn as before, which diagonals can be divided into tenths. By such means an inch can be divided into 200 equal parts: nay, more; a quarter

of an inch is frequently divided by 10 diagonals in the same manner, by which the 400th part of an inch may be indicated.

19. We have described this method as applied to the division of straight lines; but the first application of it was, we believe, to circular arcs, such as those employed on quadrants. The employment of this contrivance is now wholly out of use for circular arcs, but it is still much used for rectilinear division.

20. There have been other similar contrivances for indicating small subdivisions of space; but we must pass them over as unimportant, and proceed to describe the *Vernier*, which is of much greater interest, than any of the preceding arrangements. This was the invention of Peter Vernier, a gentleman of Franche Compté, who described the nature of the contrivance in a tract entitled, *La construction, l'usage, et les proprietez du Quadrant Nouveau de Mathematique, &c.*, printed at Brussels, in 1631. The first application of this instrument was to arcs of a circle, but as its use in dividing straight lines is more simple, we will first explain the latter office.

21. This process consists in placing in juxta-position, two graduated scales, between which there exists a known relation; and the *want* of coincidence between the dividing lines of the two scales shows by how much one division exceeds another. Let us take a familiar instance as an example. We have a line *a b*, fig. 1, of which we wish to ascertain the length: we take a graduated scale, C D, (say three inches long,) and divided into tenths of an inch, and applying one end of the line to the zero of the scale, we perceive that the other end coincides with a point between the fourteenth and fifteenth divisions of the scale, and we thus know that the line is rather more than $1\frac{4}{10}$th inches in length. This would be sufficiently accurate for ordinary purposes; but if it be desirable to estimate what portion of the next tenth of an inch is meant when we say "rather more," another scale is constructed, divided also into two equal parts, each of which parts is larger than the divisions of the original scale.

22. As nothing assists the comprehension of a written description so much as a little mechanical contrivance to illustrate it, we recommend the young student in science to furnish himself with two pieces of card, carefully graduated according to the following figure. Fig. 2, A B, is a slip of card, exactly three inches in length, and about three-quarters of an inch in width; the length being divided into tenths of an inch, of which there are of course thirty. The numbers 28, 29, 30, and 31, relate to the Barometer, to which numbers we shall presently

refer). C D is another slip of card, exactly $1\frac{1}{10}$th inch in length, and divided into ten equal parts. The two scales are numbered, the one from the bottom upwards, and the other from the top downwards. Let the short scale be called a *Vernier;* and the reader, with the two slips of card in his hand, will be prepared to follow the principle of its application as contained in the following details.

Fig. 1.

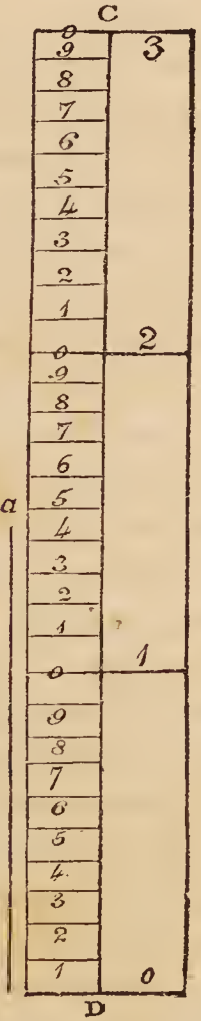
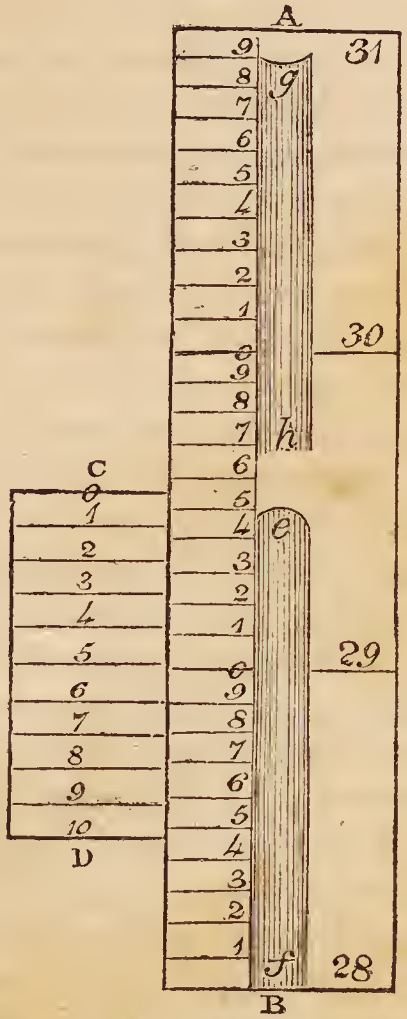


Fig. 2.



23. As ten divisions on the vernier, fig. 2, are together equal to eleven on the scale, and as those ten are all equal to each other, it follows that each division of the former must be equal to $1\frac{1}{10}$th division of the latter, or to $\frac{11}{100}$ths of an inch, which is the same thing. If, therefore, any two divisions, one on each scale, coincide, or are in a line with each other, the next pair above or below them deviates from a similar coincidence by a quantity exactly equal to $\frac{1}{100}$th of an inch; the pair two degrees removed from the first, has a deviation of $\frac{2}{100}$ths, or $\frac{1}{50}$th of an inch, and so on: thus, in our engraving, 6 on the vernier coincides with 9 on the scale; but a little consideration will show that the two figures immediately above them (5 and 0) do not exactly coincide, and that the deficiency of coincidence

between those two lines is only $\frac{1}{10}$th of $\frac{1}{10}$th of an inch, or 100th of an inch. Proceeding to the two figures next higher, which are 4 and 1, we shall have no difficulty in perceiving that their deviation from coincidence is $\frac{2}{100}$ths of an inch; in like manner, the next pair are vertically distant from each other $\frac{3}{100}$ths of an inch, and in regular succession 2 and 3, 1 and 4, 0 and 5, form couples which deviate from coincidence respectively $\frac{4}{100}$ths, $\frac{5}{100}$ths, $\frac{6}{100}$ths of an inch. But this is not all; we shall find that the same reasoning will precisely apply with reference to the pairs situated below the parallel lines 6 and 9; thus 7 and 8, immediately below them, are deficient in coincidence by $\frac{1}{100}$th of an inch; and the same series of numbers increases downwards as increased upwards in the former case. The circumstance which the reader has constantly to bear in mind is this—that a degree on the vernier is $\frac{1}{100}$th of an inch larger than a degree on the scale; from this the results detailed above follow, as a necessary consequence.

24. Now, for the application of this property:—Suppose *e f* to be the upper part of the mercurial column of a barometer, and we wish to ascertain the height which the column has attained, to $\frac{1}{100}$th of an inch. We see, in the first place, from the scale to which the barometer column is attached, that the height is somewhat more than $29\frac{1}{2}$ inches, or 29·5. In order, then, to estimate correctly how much of the next tenth of an inch is omitted in this statement, we place the zero or 0 of the vernier-scale exactly in a line with the top of the mercury*; we shall next observe that, out of the eleven lines of division on the vernier, one will coincide with one dividing line on the scale, but that *only* one can do so. In our figure the number 6 on the vernier coincides with the ninth line on the scale. Let us now determine what is the value of this figure 6 in our computation; as 6 and 9 are coincident or equal in height, 5 and 0 must, according to what was before stated, be $\frac{1}{100}$th of an inch distant from each other, 4 and 1 be $\frac{2}{100}$ths, and 3 and 2, 2 and 3, 1 and 4, 0 and 5, be respectively $\frac{3}{100}$ths, $\frac{4}{100}$ths, $\frac{5}{600}$ths, and $\frac{6}{100}$ths of an inch distant from each other. The last pair is that with which we have now to do; as 0 on the vernier is distant $\frac{6}{100}$ths of an inch from 5 on the scale, it follows that that same quantity is the distance from the top of the mercury to the figure 5 immediately below it on the scale, as the top of the mercury coincides with 0 on the vernier; and we thus arrive at the conclusion, that the height of the mercurial

* The engraver has made the end *e* about $\frac{1}{20}$th of an inch too low. The end *g* is a small fraction too high.

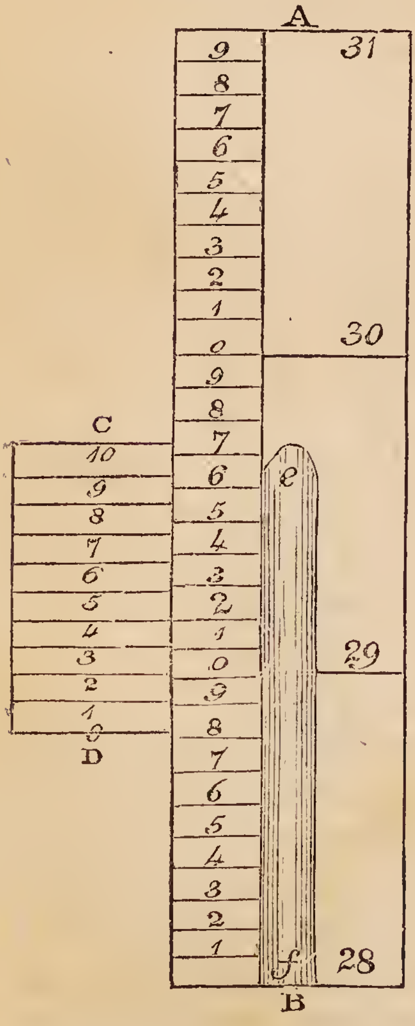
column is $29\frac{1}{2}$ inches, and $\frac{6}{100}$ths of another inch, or, expressed decimally, 29·56. The circumstance of the top of the vernier being marked 0, gives us this advantage, that the figure on the vernier, which is attached to the coinciding line, will always express the number of hundredths of an inch which are to be taken into account. The reason is obvious; from the top of the mercury to the coinciding lines there are six pairs of lines, each of which pairs deviates from coincidence by $\frac{1}{100}$th of an inch more than the one preceding it, and thus the $\frac{6}{100}$ths are formed.

25. We have chosen a case in which the upper surface of the mercury is convex, as it always is when the mercury is rising; but this mode will apply when it is concave, and the same diagram will serve to illustrate it. Suppose *g h* be the upper part of our mercurial column, and we wish to determine its height: we perceive that the indication on the scale is $30\frac{8}{10}$ inches, and a portion of another tenth, which our vernier must measure; we place the zero of the vernier on a level with *g*, the top of the mercury, and we shall then find that the line of 8 on the vernier coincides with the line of 0 on the scale. We know from this that 7 must be $\frac{1}{100}$th of an inch higher than 1, 6 $\frac{2}{100}$ths of an inch higher than 2, and so on to the top, by which we shall obtain $\frac{8}{100}$ths; accordingly 8 is the number actually attached to the coinciding line of the vernier; and we arrive at the final result, $30\frac{8}{10}$ths and $\frac{8}{100}$ths, or 30·88 inches, as the height of the mercurial column. It thus appears that it is not necessary to reckon the number of times that the corresponding lines deviate further from coincidence. Place the zero of the vernier to the extreme end of the object to be measured, and the figure attached to the coinciding line of the vernier will represent the number of hundredths of an inch which are to form part of the computation.

26. We have been describing a vernier in which the figures proceed in an opposite direction to that followed by the figures on the scale, which vernier is called *retrograde;* but there are many instruments in which the numbers proceed in the same direction, both in the scale and in the vernier. Such verniers are called *direct;* and the reader may suppose that a new or a different principle is involved in the construction of the latter; but, as it is very important in science not to consider that to be a *new* principle which is only a modification of another already employed, we deem it necessary to state wherein consists the difference between a vernier in which the figures follow the same direction as those of the scale, and a vernier in which they follow the opposite direction.

27. The whole circumstance rests upon this ground: that, when the figures proceed in opposite directions, the degrees on the vernier are larger than those on the scale; but when the figures proceed in the same direction in both, the degrees on the scale are larger than those on the vernier. This we will illustrate. In our former instance, the scale was divided into tenths of an inch, and the vernier was 1 $\frac{1}{10}$th inches in length, and divided into ten equal parts, which were individually larger, therefore, than those of the scale. But in the present instance, the vernier is $\frac{9}{10}$ths of an inch long, and being divided, as before, into ten equal parts, the length of a degree on the vernier is to that of a degree on the scale as 9 to 10; consequently a degree on the latter is $\frac{1}{100}$th of an inch larger than a degree on the former. Let us see how this operates in practice. We have (fig. 3.) a column of mercury, *e f*, whose elevation we wish to measure. We perceive its proximate height to be 29 $\frac{7}{10}$ths inches, but there is an overplus left uncomputed. We apply the vernier last described in such a manner that the figure 10 shall coincide with the top of the mercury, and we find that 4 on the vernier coincides with 2 on the scale; and we decide that the height is 29$\frac{7}{10}$ths and $\frac{4}{100}$ths, or 29·74 inches. The manner of explaining this is, in some respects, more difficult than with the other vernier, but we think the following will suffice:—If 0 on the vernier coincide with 8 on the scale, 10 on the vernier would coincide with the next higher 7 on the scale; but in order that that same number 10 should coincide with the top of the mercury, the vernier must be slightly raised, and the quantity which is so raised is reckoned by the number of degrees from the bottom before we arrive at a coinciding pair of divisions, which in this case is 4; because if 4 and 2 coincide, 3 and 1 want $\frac{1}{100}$th of an inch of coincidence, and 2 and 0, 1 and 9, 0 and 8, want, respectively, $\frac{2}{100}$ths, $\frac{3}{100}$ths, and $\frac{4}{100}$ths of an inch of coincidence.

Fig. 3.



28. It thus appears that so far as utility is concerned, it matters little what sort of vernier is employed, the only points

necessary to be borne in mind being these:—1st, that when the numbers on the vernier proceed in an opposite direction to those of the scale, 10 degrees of the former must be equal to 11 degrees of the latter, and the zero, or 0, of the vernier must be applied to the end of the object to be measured:—2nd, that when the numbers on the vernier and those on the scale proceed in the same direction, 10 degrees of the former must be equal to 9 degrees of the latter, and the division marked 10 on the vernier must be applied to the end of the object to be measured. The reader who constructs for his own use a vernier of either kind, must bear in mind, that whether it be $\frac{11}{10}$ths or $\frac{9}{10}$ths of an inch in length, it must be divided into 10 equal parts, otherwise the decimal notation, so eminently convenient in practice, would not be available for his instrument; for if 9 degrees on the vernier were equal to 10 degrees on the scale, a degree on the former would be $\frac{1}{9}$th greater than a degree on the latter; but if they were in the ratio of 10 to 11, a degree on the former would be $\frac{1}{10}$th greater than one on the latter, or expressed in proportionals—

$$\text{As } 9 : 10 : : 1 : 1\tfrac{1}{9}$$

And again—

$$\text{As } 10 : 11 : : 1 : 1\tfrac{1}{10}$$

And this is the proportion for which the decimal notation is so available.

29. The vernier, as we have hitherto considered it, is applicable to rectilinear divisions. It can, however, as before observed, be applied with equal facility to circular divisions, such as those which form essential parts of the quadrant, sextant, and instruments employed in the measurement of angles. The vernier is, in such cases, a segment of a circle which is concentric with the segment of the circle forming the scale. But here we have to allude to a circumstance which gives rise to a different graduation of the vernier. In our previous details, an inch in the scale is supposed to be divided into 10 equal parts, and the vernier to be constructed with degrees, either $\frac{1}{10}$th greater or $\frac{1}{10}$th less than those on the scale; but it is obvious that any other standard may be assumed, according to the necessities of the case: for instance, a degree of a circle is neither divided into 10ths nor 100ths, but into 60ths,—60 minutes being equal to 1 degree; consequently the decimal notation would lead to confusion in the sub-division of the scale. Whether or not it would be desirable to substitute 10ths, 100ths, 1000ths, &c., of a degree for the present series of minutes, seconds, &c., in English scientific observations, is a separate question: we are decidedly of opinion that it would; but, as

things are at present, the vernier attached to graduated arcs must be regulated according to the sexagesimal system, unless the degree itself be previously divided into three or six equal parts. Thus, we have now before us a quadrant, constructed by Nairne, in which each degree of the arc is divided into three equal parts, and to this is attached a vernier so graduated that 20 of its divisions shall be together equal to 19 of those on the arc: a division on the former, therefore, is $\frac{1}{20}$th smaller than a division on the latter, and by its means we can measure $\frac{1}{20}$th of $\frac{1}{3}$rd, or $\frac{1}{60}$th of a degree, which is equal to one minute, or, (expressed in the usual symbols,) $0° 1'$.

30. As we have now shown that the vernier may be divided into either 10 or 20 equal parts, so it might easily be shown that it admits, theoretically, of a division into 100 equal parts in a similar manner; and that, by its means, $\frac{1}{1000}$th of an inch could be measured. Thus, suppose we had a scale 10 inches in length, and divided into 10ths of an inch, of which of course there would be 100; and that we construct a vernier either $10\frac{1}{10}$th inches, or $9\frac{9}{10}$th inches in length, and divided in 100 equal parts; it is obvious that if any line on the vernier coincided with a line on the scale, the next pair above them would deviate from coincidence by a quantity equal to $\frac{1}{100}$th of $\frac{1}{10}$th of an inch, or $\frac{1}{1000}$th of an inch. In fact, we may state generally that the only limit to the micrometrical power of the vernier is the limit to our power of mechanical contrivance; for, as the lines which we engrave on our scales have an appreciable thickness, any quantity less than that thickness cannot be measured by its means, even admitting the accuracy of division to be rigorous. Supposing, however, the graduation to be correctly done, the power of the vernier is greatly increased by the following little contrivance.

31. The vernier is, in some delicate instruments, moved by means of a screw, which, passing through a female screw cut in a fixed collar, is so arranged that, in turning upon its axis, it moves either backwards or forwards. The other end of the screw, instead of the usual thread, (which here terminates about half-way up,) has, cut upon it, the divisions of the vernier. On taking hold of the head of the screw, a very slight turn will be found to alter the relation of the vernier to the scale; and the advantage gained is, that the screw enables the observer to adjust the one to the other with great nicety: if the divisions be very small, the eye may be assisted in this adjustment by the employment of a small double-convex lens attached to the instrument.

32. Here it will be seen that the screw is only employed to produce a slow and gradual motion; but if we suppose the screw to have been cut with perfect accuracy, and its threads to be quite regular, it follows that the very motion of the screw round its axis can be made subservient to the purposes of subdivision. To effect this we must suppose two things,—1st, that the two screws are accurately fitted to each other; 2nd, that the threads of the screws are perfectly homogeneous. These conditions fulfilled, then it follows that for every turn of the screw upon its axis, the vernier will advance or recede a distance which is equal to that contained between two contiguous threads of the screw; and for a half or quarter-turn, the advance or recession will be the half or the quarter of this interval. It becomes easy, then, to determine these fractions, by tracing upon the border of the head of the screw a circular division of equal parts, which shall bear a known relation to the principal scale; for if this graduation of the circle be into 100 equal parts, in turning the screw one of these parts, the motion of the vernier will amount to only the $\frac{1}{100}$th part of the distance between two contiguous threads of the screw; so that, supposing the vernier and the scale to which it is attached to be adapted to the measurement of $\frac{1}{1000}$th of an inch, the motion of the screw through one of its divisions will give the 100,000th part of an inch as the result of the combined action of the vernier and its screw. Thus, it will be seen how an inch may be divided, by a nice adaptation of the vernier, into a very large number of equal parts,—from 100 to 100,000.

33. We shall be understood as meaning to imply rather what might be accomplished if the mechanical ingenuity of the workman were greatly increased; and not so much what we are in the habit of seeing in instruments actually constructed. The art of graduating such instruments has, however, been brought to great perfection; and we should not be justified in hastily assigning any given limit to the powers of the workman. The Rev. Mr. Pearson, in his work on Practical Astronomy, says "In Troughton's reflecting circle, of five inches radius, though a space of 30′ reads as a degree, the vernier indicates 20″ in an arc, $= 19° 40′$, divided into 59 parts, coextensive with 60 on the vernier; and, in a brass sextant which he divided, and which is now in my possession, an arc of 7° 6′, with ten divisions in a degree, has 71 divisions, coextensive with 72 on the vernier, which therefore indicates $25560 \div 5112 = 5″$. In an 18-inch circle, attached to a portable transit-telescope, a vernier with

100 divisions, measuring 99 on the limb, having 12 divisions in a degree, indicates a quantity so small as 3″."

34. In very delicate instruments employed in Astronomy, it is found that the vernier, by moving on the graduated limb, is apt to obliterate or obscure the divisions, owing to intervening particles of dust, &c. To obviate this, many of the continental instrument makers execute the graduations of the vernier on a circular revolving plate, depressed to the same plane with the graduated circle to be indicated; in which construction the chamfered edge is not necessary.

35 In some of the more delicate verniers, the indications are read off by the aid of single microscopes, provided with reflectors of plaster of Paris, to illuminate the very minute marks engraved on the scale and vernier.

Before we conclude our subject, we will present a few details respecting the mode of graduating, or cutting the marks which indicate the divisions of verniers and similar scales.

36. This operation is performed with machinery more or less complex, but it will be sufficient to give a general idea of the process. In graduating a circle, a metallic plate, varying from 14 to 30 inches in diameter, is laid upon the plate to be graduated. An index, or straight edge, runs from the centre to the circumference of the dividing plate, along the edge of which the dividing knife passes, and makes a cut on the arc to be graduated. The dividing plate is variously graduated, according to the purposes to which it is to be applied. The graduating knife is of the best steel, with a beech handle. The cutting edge of the knife is of exactly the same thickness that the divisions are intended to be of, and perfectly straight. The edge is not sharp like that of a razor, but rounded, so as to present a semicircle to the surface of the plate. The back edge is one-fifteenth of an inch thick; and the extreme end forms an angle with the blade equal to 70°.

37. In common engraving, the tool is pushed onwards, and cuts out a film of the substance, but in graduating, the tool is drawn towards the workman, and ploughs a furrow, which raises a bur on each side, which is scraped off. Although much delicacy is required in the operation of graduation, yet practice enables the workman to keep pace with a common seamstress; —that is, the one will engrave lines as fast as the other can make stitches.

38. In box-wood scales, the divisions are blackened by powdered charcoal and linseed-oil. In ivory scales, the divisions

are covered with lamp-black and hard tallow, or bees' wax and olive-oil. When the divisions are filled, the remainder is carefully cleaned off.

39. Ramsden devised an engine for cutting straight and parallel lines. It consisted of a strong plate of brass, moveable on two edges of an iron frame. To facilitate its motion, the friction was diminished by the application of three rollers to the under-side of the plate. One edge of the brass plate was ratched, or cut into teeth, of which there were twenty in an inch; and it was moved along the iron frame by an endless screw, having the same number of threads in an inch. These threads fitted into the teeth in the brass plate. Each revolution of the endless screw round its axis, moved the plate one-twentieth of an inch along the iron frame. A small wheel was fixed on the end of the screw, having its circumference divided into fifty parts, which were again subdivided into five parts by a vernier. When therefore the screw was turned on its axis, one of the primary divisions, the plate was moved $\frac{1}{1000}$th of an inch along the iron frame. If the screw were turned to the coincidence of one division on the vernier, the plate would be moved $\frac{1}{5000}$th of an inch along the iron frame; and the line on the plate to be divided, (which terminated the space moved over by the brass plate) was then drawn on it, or on any instrument fastened on the plate, with great accuracy, by a point or tracer fixed in a proper frame, whereby it has a free linear motion, without any lateral shake.

40. It is by some such contrivance as this, with the aid of exquisite manual dexterity, that the minute lines on the *iris ornaments* of Mr. Barton are engraved, to which we allude in our article on the "Soap-bubble" (33).

41. Similar engines have likewise been constructed to facilitate the graduation of circular arcs, the most celebrated of which is that of Mr. Troughton:—machinery of the most complex description is adopted for this purpose, and the instruments graduated by that eminent artist are highly valued throughout Europe. Mr. Troughton has stated that fourteen years of incessant practice are necessary, before this difficult art can be acquired.

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42. The study of the principle of any instrument will lead us into many interesting details, not in general considered as appertaining to the instrument. In this article our object has not been to supply a minute description of the elaborate pieces of apparatus, and the many ingenious contrivances, which science,

art and industry have in store for the attainment of that important object and aim of science; viz. accuracy: this, however delightful and important, would have led us too far: our desire has been to impress upon the student's mind the *principle* of the vernier; for he must never forget that the possession of a number of facts, unconnected by principles, is like the possession of a fund of anecdote and wit; it is merely *amusing*. Society is now generally becoming attached to the *utile* as well as to the *dulce:* it will applaud that which amuses the idle hour, but it will generally value and respect that which can render the idle hour not merely *amusing*, but *profitable*.

43. The vernier may be considered as a step towards the knowledge of that world of minute objects, which the microscope opens to our view; and which is as much worthy of our notice, as the vast and sublime scale on which astronomical phenomena are presented to our ken through the agency of the telescope. The latter instrument, as an intelligent divine remarks, leads us to see a system in every star. The microscope leads us to see a world in every atom. The one teaches us, that this mighty globe, with the whole burden of its people and of its countries, is but a grain of sand on the high field of immensity. The other teaches us, that every grain of sand may harbour within it the tribes and the families of a busy population. The one tells us of the insignificance of the world we tread upon. The other redeems it from all its insignificance; for it tells us that in the leaves of every forest, and in the flowers of every garden, and in the waters of every rivulet, there are worlds teeming with life, and numberless as are the glories of the firmament. The one has suggested to us, that beyond and above all that is visible to man, there may be fields of creation which sweep immeasureably along, and carry the impress of the Almighty's hand to the remotest scenes of the universe. The other suggests to us, that within and beneath all that minuteness, which the aided eye of man has been able to explore, there may lie a region of invisibles; and that, could we draw aside the mysterious curtain which shrouds it from our senses, we might there see a theatre of as many wonders as astronomy has unfolded, a universe within the compass of a point so small, as to elude all the powers of the microscope; but where the wonder-working God finds room for the exercise of all his attributes, where He can raise another mechanism of worlds, and fill and animate them all with the evidences of his glory.

VI.

THE COMPASS.

When, by his lamp, to that mysterious guide,
On whose still counsels all his hopes relied,
That oracle to man in mercy given,
Whose voice is truth, whose wisdom is from heaven,
Who over sands and seas directs the stray,
And, as with God's own finger, points the way,
He turned; but what strange thoughts perplexed his soul,
When, lo, no more attracted to the Pole,
The Compass, faithless as the circling vane,
Flutterèd and fixed, fluttered and fixed again!
At length, as by some unseen Hand imprest,
It sought with trembling energy the West!
"Ah no!" he cried and calmed his anxious brow,
"Ill, nor the signs of ill, 'tis thine to show;
Thine, but to lead me where I wish to go!"

ROGERS.—*The Voyage of Columbus.*

1. WHEN we cast a hasty retrospect over the History of Civilization, the mind is arrested by, and fixes itself on, certain prominent points, which seem to constitute the motive powers whereby man's advance towards perfection is insured. There are certain grand epochs in the history of the human race, for which preceding ages seem to have been preparing us; that is, civilization has advanced up to a certain point, at which it might have remained stationary, or even have retrograded, but for some splendid discovery or grand invention, which not only gives to mankind a vantage ground, whereon to contemplate the future,—but it ameliorates the condition of the whole human family, by opening new sources for the exercise of ingenuity; improving the arts of life, and thereby affording fresh comforts and conveniences to the multitude; extending the boundaries of the sciences, whereby the power of the human mind is increased to an almost illimitable extent; and, finally preparing the way for new discoveries, appliances, and inventions, which bring in their train a long list of blessings and advantages of which the members of the preceding age were not conscious.

2. Nature, in all her works, is very sparing of prodigies. Though her admirers are so numerous, that the number includes

all those who delight in the good, the beautiful, and the true, yet how limited is the number of her confidants! Those to whom she reveals some of her most precious secrets, that they may be diffused among, and bless mankind! We may reckon centuries upon centuries, and count but few in the long lapse of ages who deserve the title of confidants of Nature. One such individual is, indeed, a prodigy. Such a being, as can impart to mankind the art of printing;—another who can demonstrate the laws of the universe in a sublime theory of gravitation; or grasp the sun-beams and force them to reveal their secrets:—another gifted mortal who can make the giant steam become the obedient servant of his fellow men:—and yet another who can offer the means of guiding the prow over that path which leaves behind it no trail:—these are men whom nations are proud to call their own. But they belong to no nation;—the world is their birth-place;—the world is the scene of their operations;—the world is their shrine at which nations, benefitted and exalted, appear, to offer the tribute of admiration, gratitude, and praise.

3. We are about to call the attention of the reader to the *Compass*, and the laws by which its action is regulated. The inventor of this invaluable instrument is unknown; and although we cannot render honour to his name, yet the invention remains to us, diffusing its blessings over the whole world;—a proof, if proof be wanting, of the immortality of the works of a great mind, and of the instability of human names and titles. Although it is natural in us to honour and respect the benefactor of his species, yet the example before us proves that this is not necessarily a part of Nature's plan. The Almighty, in selecting one to be the means of communicating certain benefits to his species, did not intend that the medium should be honoured, so much as the benefit conferred, and Himself the author and giver of it, and of all good gifts. Let us not, therefore, fall into the too common error of "worshipping the creature more than the Creator," but rather carry our adoration up to the throne of Him who made man after His own Image; and when we speak of Nature, as it were in terms of fond admiration, for an exalted and omnipotent source of good, let us never lose sight of the important Truth that,

> Nature is but a name for an effect
> Whose cause is God.

Section I. The Magnet.

4. The ancient Greeks, who loved to clothe truth in the multiform garb of fancy and imagination, represent one Magnes, a shepherd, leading his flocks to Mount Ida; he stretched himself upon the green sward to take repose, and left his crook, the upper part of which was made of iron, leaning against a large stone. When he awoke and arose to depart, he found, on attempting to take up his crook, that the iron adhered to the stone. He communicated this fact to some philosophers of the time, and they called the stone, after the name of the shepherd Magnes, *the Magnet*, which it retains to the present day. It is, however, denominated among many nations the *love-stone*, from its apparent affection for iron.

5. The term *native magnet* is applied to the *load-stone**, which is an iron ore, consisting of the protoxide and peroxide of that metal, together with a small proportion of quartz and alumina. The magnetic iron ore is abundant in various parts of the world, and constitutes a most important ore of that metal. India and Ethiopia formerly furnished great quantities of this native magnet. Tiger Island, at the mouth of the Canton River in China, is in great measure made up of this ore; as mariners infer from the circumstance of the needles of their compasses being much affected by propinquity to this island. We find that, in the earliest times, there were reputed to be five distinct kinds of load-stone,—the Ethiopian, the Magnesian, the Bœotic, the Alexandrian, and the Natolian. The ancients also believed the load-stone to be of two species, male and female. We read of its being used, in the middle ages, medicinally;—to cure sore eyes, and to produce purgation. Even in modern times, plasters have been made from this ore; and much other quackery has been perpetrated by its means.

6. The most important quality of the load-stone, is that of communicating to iron or steel a property, which itself possesses, of attracting iron and ferruginous bodies, and also of repelling them under certain conditions; the developement and consideration of which, constitutes the science of Magnetism.

7. We will suppose then that a steel needle is suspended from its centre, and free to move in all directions. Such suspension must of course be effected by a thread:—the usual

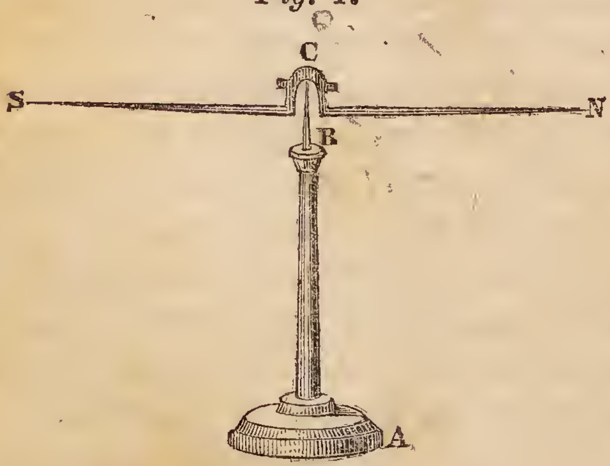
* This appears to be derived from an Icelandic term, "Leider-stein," signifying the *leading-stone*. It was designated by the term STONE from the stony particles found connected with it.

mode of suspension is by laying it gently, at its centre, on a fine point:—and the primitive way of suspending it was by leaving it to repose itself on water. The various properties of this needle we may consider under the following heads, viz., 1st, The direction of the needle; 2nd, Its attraction of unmagnetised iron; 3rd, Its attraction and repulsion of magnetised iron; 4th, Induction, or the power which it possesses of rendering iron magnetic; 5th, The variation of the needle; and, 6th, Its dip.

8. i. THE DIRECTION OF THE NEEDLE. When the magnetic needle is left free to move, and iron and other bodies likely to disturb it are withdrawn from its vicinity, one of its ends points towards the north, and the other end towards the south. The end which tends towards the north is called (incorrectly, as we shall presently show) the *North Pole;* and the end pointing towards the south is called (also incorrectly) the *South Pole.* A line joining these two poles is called the *axis* of the magnet; which poles are separated at the centre of the magnet by a line called the *Neutral line*, at right angles to the axis. Sometimes the terms *Boreal* and *Austral* are substituted for *north* and *south:* the former term being derived from the name given by the ancients to the *north* wind; and the latter from the name given to the *south* wind.

9. When several magnetic needles, moving freely in a horizontal plane, are placed so that they cannot influence each other, they take parallel directions: poles of similar denominations being, of course, directed the same way.

Fig. 1.

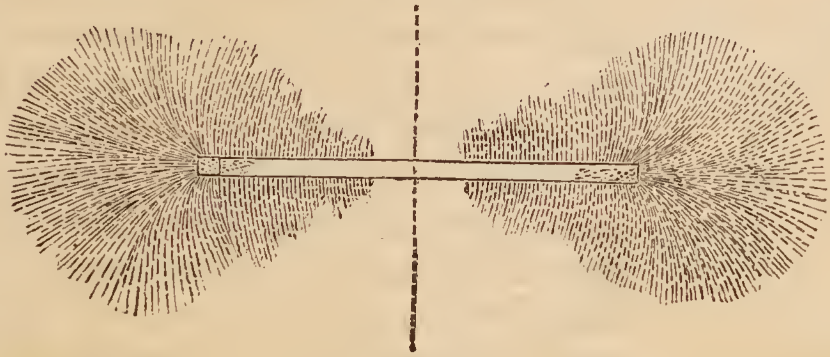


10. Figure 1, represents a very convenient method of exhibiting the direction of the magnet. From a stand, A, proceeds an upright cylinder of wood, or metal not ferruginous, which contains in the direction of its length a wire, B, which is brought to a fine point at the top. At the centre of the magnet, C, a hole is drilled and an agate cap fitted in; into the hollow of which the pointed wire, B, enters and supports the magnet, which, being free to move with very little friction, readily yields to the slightest influence, moving in the present case in a horizontal

plane. When the needle is first mounted, it oscillates to and fro several times, and at last settles into the direction of (nearly) north and south, as above described. This tendency of the needle to settle into one position in preference to any other, is called its *Polarity*.

11. ii. The attraction of the magnet for unmagnetised iron, is a well known and familiar fact. This seems to be the sum of the knowledge possessed by the ancient philosophers on this subject. No trace of evidence exists, which can lead us to suppose that they were even aware of the magnet having any especial tendency. This attraction may be shown in a pleasing

Fig. 2.



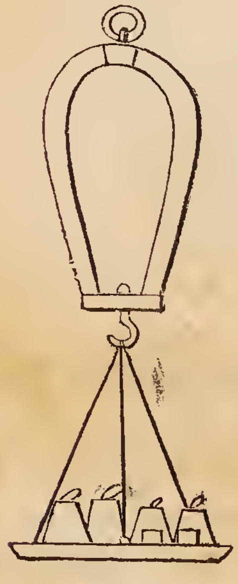
manner by employing a bar magnet, that is, a magnetised bar of steel which has the form of a very long rectangle, at one end of which a notch is cut to indicate the North Pole. If this magnet be placed on paper and iron filings be sifted upon it, it will, when the filings that are not attracted are shaken off, present the appearance of Figure 2.

12. It will be seen that the filings are collected as filaments, nearly perpendicular to the surface of the magnet; that they exist in greatest quantity at and about the poles, and decrease towards the centre of the magnet; while at the centre there is no attractive power whatever. The attraction therefore is strongest at the poles. In this experiment, the beautiful curves, which the filings describe, will not thus be produced to so great an extent as shown in the figure; but they may be obtained by the following contrivance. A large sheet of paper is to be stretched in a frame of wood, so that when placed flat upon a table it may present a smooth horizontal surface. The bar magnet is to be placed under this surface, so as just to touch it, but not to disturb the horizontal surface by pressing it up. Iron filings are then to be sifted upon the paper in a thin layer: a few gentle taps given to the under surface of the paper wil cause it to vibrate, and the magnetic force will dispose the filings into those beautiful and regular curves as shown in the figure.

13. In this experiment, every particle of iron which enters into the formation of a curve, immediately becomes, as we shall see further on, a perfect magnet; indeed, it has been laid down as one of the fundamental laws of the science, that every particle of iron which is in the vicinity of a magnet, becomes a magnet. This definition seems to imply that absolute contact is not necessary, in order to manifest the attraction between the magnet and iron or steel; for these small bodies or particles are visibly affected, even though a solid substance interposes between them and the magnet.

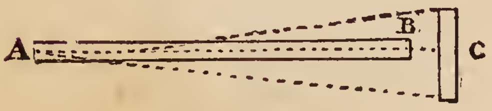
14. Magnets are sometimes made in the form of a horse-shoe as in Figure 3, by which the two poles are brought near each other, and are connected by means of a piece of soft, that is, *unannealed* or *untempered* iron, called an *armature*, or *keeper*, which is very favourable for increasing the strength of the magnet when not in use*; and it also enables us to apply the two poles to the purposes of experiment, as shown in the figure, where from a hook attached to the armature, there hangs a scale, in which weights are placed to the amount of many pounds. Before applying the armature we may place on the smooth ends of the poles a thin piece of wood, or paper, and we shall find that the armature will still adhere with considerable force, proving, as stated above, that contact is not necessary in order to display the attraction between the magnet and ferruginous bodies.

Fig. 3.



15. The advantage of the horse-shoe form, by which an armature can be so conveniently applied, may likewise be illustrated thus:—the attraction which a magnet exerts upon an adjacent piece of iron, is manifested perpendicularly to the surface of contact between them; or, rather the resultant of all the magnetic force existing in the magnet is in a line perpendicular to the surface of contact. Now, if we suppose A B, figure 4, to be a straight magnet, and C, a piece of iron near it, the end, B, will attract it strongly because

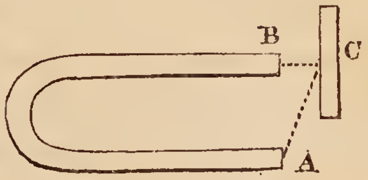
Fig. 4.



* The ancients believed that the magnet fed upon iron, and thus became stronger.

of its proximity; but the end, A, will attract it in some degree, because the line of attraction (denoted by the dotted line) is also perpendicular to the surface of C. If, however, the bar be bent into the form A B, figure 5, and the iron, C, be applied near B as before, we perceive that the line joining the centres of B and C, is as pendicular to the surface of each as before; but with respect to the end, A, the case is altered; the feeble attraction of A for C is rendered more feeble by the great obliquity with which the force is directed. When we come hereafter to show the antagonism of the two forces in a magnet, the importance of this circumstance will be more fully appreciated.

Fig. 5.



16. Bar magnets are usually sold in pairs, enclosed within a wooden case, and the opposite poles are connected by means of armatures, as in figure 6.

Fig. 6.

17. Another great use of armatures is, that the polarity of a magnet is often diffused over a great extent of its surface; and the armature becomes the medium whereby, in consequence of the tendency of the magnetic forces* for it being constant, these dispersed forces are collected at length at the poles, where they remain after a lapse of time. The same remark applies to the armature on the horse-shoe magnet.

18. It sometimes happens, that a single bar-magnet has several poles intermediate between the two extreme poles. Such a magnet is usually weak and inefficacious; but may be improved by connecting it by armatures with another magnet of the same size.

19.—iii. If, when the needle, as represented in figure 1, is at rest and pointing towards the north, we attach to its north pole a small piece of paper, in order that such pole may be recognized without difficulty, and hold at the distance of a few feet, and at right angles to the pole of the needle, the north

* As we shall frequently have to employ the term *force*, the reader is informed that these three elements constitute a force,—direction, intensity, and the point of application. It will also be remembered that a body, which is moveable round an axis, cannot receive any motion from a force acting parallel with such axis. The importance of these definitions will be seen as we advance.

pole of a bar-magnet,—the needle will begin to move in a horizontal plane, the north end being repelled and the south end turning slowly round towards the north end of the bar-magnet. If the latter approach nearer to the north pole of the needle, we shall find it impossible to bring these two similar poles into contact by their own spontaneous action;—there will be a constant repulsion; but we shall find that the south end of the needle will be as actively attracted by the north end of the magnet, as the north end of the needle was, in the former case, repelled. We shall also find that a decided attraction will exist between the south end of the magnet and the north end of the needle. Hence we get a general law in all magnetic action, viz., that two north poles repel each other; that two south poles repel each other; but that a north pole attracts a south pole, as also, that a south pole attracts a north pole.

20. The foregoing experiment, and the important law deduced from it, show us why that end of the magnet called the north pole is a misnomer. If we consider the globe, which we inhabit, to be a magnet, we shall find, and in fact we do find*, two poles, called the magnetic poles of the earth, in accordance with which every magnet upon its surface, free to move, directs itself; and this direction depends, as we shall see further on, upon the situation of the magnet, with respect to such magnetic pole. Now, as the experiments of the philosopher are only representations, in miniature, of the grand processes of Nature; and as a natural law applies equally to small and grand effects, we learn from the experiment above, that the north magnetic pole of the earth does not attract the *north* pole of a magnet upon the earth's surface; but on the contrary, repels it. The pole of the magnet which the north magnetic pole of the earth attracts is, in fact, the south pole; and a traveller, furnished with a needle free to move in a vertical plane on a horizontal axis, as we shall hereafter explain, would find that on journeying from the equator to the north magnetic pole, the real *south* end† of the needle would bend down more and more, until on arriving at the north magnetic pole, the needle would be erect,—the real south end pointing downwards; thus indicating the attraction of this pole for it. Whereas, if he visited the south magnetic pole of the earth, the real north end of the

* The more rational of the philosophers of the middle ages had already conceived the existence of a great natural load-stone near the north pole of the earth.

† The *north* end as marked by the instrument-maker, and so called in common discourse.

magnet would point downwards. From this we learn, that that end of the needle which points towards the north is actually its south pole; and the other end pointing towards the south, is its north pole. The reader is requested to bear this distinction carefully in mind; for although the usage of many years has so mixed up the error in every thing relating to magnetism, that it would be difficult now to eradicate it; yet if the error be clearly pointed out and understood, no evil consequences need result. It will, of course, be understood that we must also accommodate ourselves to the prevailing mode of designating the poles of the magnet.

21. In the experiment alluded to above, we have seen that a magnet acts upon the poised needle at a distance; this action takes place even through paper, wood, glass, flame, water, &c. When two needles are employed, their reciprocal action decreases in the inverse ratio of the square of the distance.

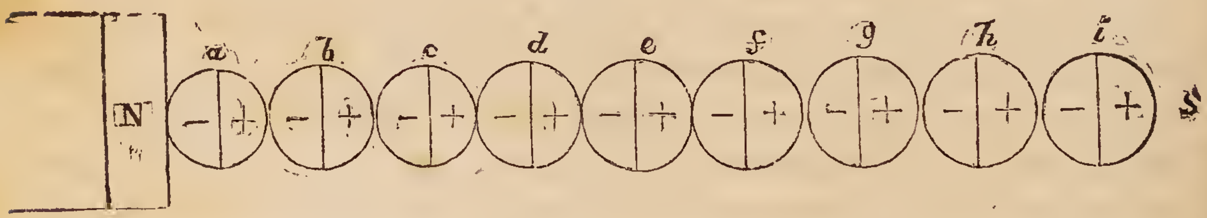
22. It is on the principle of attraction and repulsion, that numerous magnetic toys are constructed; such as the magnetic ship, fish, mermaid, swans, &c. A magic spider is also made to move over a dial-plate, and perform various arithmetical processes at the bidding of the spectators; such as telling their ages, &c. This is done by means of a magnet concealed behind the dial-plate, and secretly moved by the exhibitor. In this way science explains numerous other reputed magic performances.

23. iv. Induction. We have seen (8) that in every magnet there reside two forces, separated by a neutral line; which forces appear, at first view, to be identical, since both of them exert the same influence upon unmagnetised iron; but we have seen that upon magnetised bodies the action is marked by repulsion in certain cases, and by attraction in others. The neutral line separates two antagonistic forces, and forms the limit between them; and this is the principal reason why it constitutes a *neutral* point. The two magnetic forces, like the two electric forces, tend to neutralize each other: and if it were possible to include within a magnet of any given size, another magnet of precisely the same size and intensity—the two magnets, with their poles in opposite directions, would present a compound magnet, absolutely devoid of any magnetic property whatever. This is to suppose an impossible case; since one magnet cannot, of course, be enclosed within another of precisely the same size; but we give it simply as an illustration of the tendency of dissimilar poles to destroy each other's action. By the mere superposition of one magnet upon another of equal size, with dissimilar poles in contact, the neutralization cannot be

quite complete; because the different parts of one of the magnets do not meet with the corresponding parts of the other magnet; but in this latter case, the reduction in intensity is very great, as we shall presently see (26).

24. There is a remarkable distinction between the action of a permanent magnet, (that is, a magnet which always retains its magnetic power,) upon steel and upon soft iron. We have seen the action of a magnet upon iron filings, and we have stated that in order to produce the magnetic curves by means of such filings, it is necessary that each particle of iron should become, by induction, a temporary magnet. Thus, suppose, in fig. 7, N S to be a number of particles of iron attached to the north pole of a magnet N. The first particle *a* in immediate contact with N, is magnetised by the induction of the magnet N, and has two poles separated by a neutral line: a south pole marked −, and a north pole marked +; which latter pole attracts a particle *b*, and by induction, this second particle is attached to the first by its south or − pole; and so on with the rest. If now the magnet were withdrawn from −*a*, and removed altogether, the particles of iron *a*, *b*, *c*, &c., would fall down inert, and altogether devoid of magnetic force.

Fig. 7.



If, instead of particles of iron, we place at or near N, a piece of iron wire, the latter becomes, by induction, a magnet, so long as its proximity to the permanent magnet N is preserved. But it ceases to display any magnetic power when removed from the magnet; whereas, steel filings, or steel wire, by contact with a permanent magnet, become themselves permanent magnets also; and although mere contact, or proximity, is not alone sufficient for bestowing upon steel high magnetic powers, yet the simple fact that they do so become permanently magnetic, and that soft iron does not, is one among the most remarkable and important of magnetic phenomena.

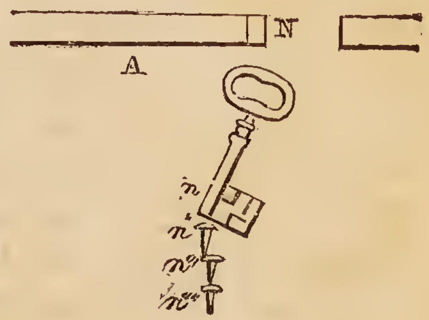
25. Fig. 7 will also serve to illustrate a convenient mode of considering the propagation of magnetic action. Instead of supposing the small globules to be particles of iron, we may suppose them to be magnified representations of the ultimate particles of bodies, each particle having a portion of magnetism

belonging to itself. Any cause which disturbs the equilibrium of the magnetic fluid (we call it *fluid* for want of a better name,) in the first particle, will act upon the next particle by induction, and throw it into a positive and negative (or plus and minus) state, as was the case with the particles of iron; and this disturbance would be communicated from end to end of a row of particles. If now we suppose that a piece of iron be made up of a row of particles, such as in the figure; we see that the left side of the first particle is in a negative state, and that the right side of the last particle is in a positive state; the two states being separated by a neutral line: and as it is principally at the ends of a piece of iron, that any magnetism which it may have acquired is manifested, we see that whatever effect would be produced by the left end of the row, a contrary effect would be produced by the right end, without involving any particular hypothesis as to what that action or effect may be. The reader may thus acquire a convenient mode of representing to his mind the manner in which induced magnetism may travel through a piece of iron, without the necessity of adopting any particular theory of the source or nature of magnetism.

26. The properties of induction that we have thus announced, have been illustrated by various experiments of a highly instructive nature, from which we select one or two examples.

In fig. 8, let A represent a bar-magnet resting on a table, with its north pole projecting over the edge. If we hold a key near such north pole, we shall find that a nail presented to the end of the key will be suspended, in consequence of its induced magnetism. To the first nail a second, a third, and a fourth may be successively attached. The lower end of the key n, and the points of the nails n'' n''' n'''', being respectively, north poles; each little nail represents a particle of matter, according to our previous illustration. The upper ends of the key and of the nails are respectively, south poles. By gradually removing the key and the attached nails from the magnet N, they will all get beyond its influence, and consequently, losing all magnetic power, the nails will fall to the ground.

Fig. 8.



27. If, instead of holding the key at a certain distance from the magnet we at once bring it to actual contact with it, at N, and apply the nails to the key; and then place the south pole of another magnet near to, or in contact with, the north pole of

the former magnet, the handle of the key, being also a south pole, will be repelled, and the north end N of the first magnet will be attracted by the south end S of the second; consequently, the key, with its appendages, will fall. In the one case, the south pole S of the second magnet being more powerful than the south pole of the key, the latter is repelled by a greater force than it can of itself exert; and in the second case, the two opposite poles N and S of the magnets exert a powerful, and indeed, a total attraction for each other, and the key, having no force to keep it suspended, necessarily falls, in this as well as in the former condition.

28. The following is also an instructive example of the neutralization of induced magnetism. If we take a piece of soft iron, of the form of the letter Y, and connect one of its forks with the north pole of a bar-magnet, its end will also become a north pole, and will sustain the key and nails, as in the last experiment. If now we bring the south pole of another magnet in contact with the other fork, the north pole at the end will be immediately transferred to the end of the second fork, and the key and nails will fall. We use bar-magnets in particular, as affording the greatest facility for the operation.

29. Such, then, are a few of the simple consequences of induction, and of the law that dissimilar poles attract, and similar poles repel, each other. But, experience teaches us, that the amount of attractive force between two dissimilar poles, is considerably greater than the repulsive force between two poles that are similar. When two opposite poles are in contact, there is a tendency in each magnet to increase the power of the other, by developing opposite magnetism in the adjacent halves, whereby their mutual attraction is increased. But when two similar poles are brought together, the action of either half, brought in contact, tends to develope in the same half an opposite magnetism to that which it really possesses, and thus to diminish the effect of the two similar repelling forces. This may be well illustrated, by recurring to our first experiment, where a large bar-magnet is supposed to be presented to a small poised needle. We have said, that it is impossible, in such case, to bring two similar poles in contact by their own spontaneous action, by which we did not intend to imply that such contact could not be effected by any means; for if the north end of the needle be held stationary, and the north end of the bar-magnet be then applied to it, we shall find, on relinquishing our hold, that no repulsion will be manifested; but on the contrary, the two similar poles will remain in contact. We shall, however, pro-

bably see on afterwards examining the needle, that its poles are reversed; that is, the north pole of the needle, which was forced into contact with the same pole of the bar-magnet, has become a south pole, and its other end a north pole. In this case, it is simply a question of attraction between a strong and a weak force; the magnet attracts the similar end of the needle almost as it would a piece of unmagnetised steel. But in the case before us, the weaker force is destroyed, and regarding the needle simply as a piece of steel, magnetism is induced again, which it continues to retain.

30. Having seen, then, that by induction a permanent magnet confers upon iron and steel properties similar to itself; which in the first case are not retained, while in the second case they are retained; it may very naturally be inquired, whether the magnet itself loses aught of its power in bestowing such power upon other bodies. It does not lose power; but, on the contrary, if judiciously exercised, it gains strength in proportion as it imparts strength to other bodies. This is a beautiful and remarkable example, to which we can find no complete analogy, save in the human mind; which, like the magnet, in imparting to others its own stores, does not lose the possession of them itself, but on the contrary, improves them, and exercises, (if we may be allowed the expression), that charity of intellect which is twice blessed, for it *blesseth him that gives, as well as him that receives.*

31. When we wish to ascertain whether a piece of metal or a mineral is magnetic, all that is necessary is, to present it to one of the poles of the poised magnet (fig. 1.). If attraction only, be exerted at both poles, we then conclude that the substance so tested is not magnetic.

32. In order to prove that a piece of soft iron attached to a magnet, does not deprive the latter of any of its attractive power, let us cut off a piece of the attached iron by means of a pair of cutting-pliers, and the piece so cut off will not display any magnetic force, while the fragment which remains attached, will be actively magnetic.

33. In referring to the properties of the magnet which we have thus briefly developed, we have now to remind the reader that magnetic phenomena are referred to the action of two subtle fluids, endowed with opposite properties; which fluids are supposed to surround the molecules of iron and steel, but without the power of passing from one molecule to another; the reunion of which fluid would form the magnetic fluid in an isolated state. In the science of Electricity, (according to the

most favoured hypothesis,) two dissimilar fluids, the vitreous and the resinous, are supposed to exist, which neutralize each other, in order to form electricity in equlibrium. So also, the magnetic fluid is supposed to consist of two fluids, the northern and the southern, or Boreal and Austral, which mutually attract each other and form magnetic electricity in equilibrium.

34. This valuable property, then, which the magnet possesses of imparting to other bodies a power similar to its own, (which property is known under the general term *induction*), is considerably modified by the nature of the material upon which it is exerted. A bar of soft iron is a magnet immediately, by contact, but continues so only as long as it is connected with a permanent magnet; a bar of hard or tempered iron, or of steel, slowly receives by contact, the permanent influence of the magnet; but when once developed, it retains this influence long after separation from the magnet. This, then, constitutes an artificial magnet, in contradistinction to the load-stone or natural magnet. Hence we derive certain principles relative to the application of magnetism to ferruginous bodies:—that, as soft iron readily receives and parts with the magnetic current, it is a good conductor of magnetism;—again, that as hard iron or steel admits the magnetic current with difficulty, and with difficulty resigns it, it is a bad conductor of magnetism. The ease or difficulty with which the iron takes or loses the magnetism, is inversely proportionable to its hardness. Some cause, then, exists, which prevents the dissipation or decomposition of the acquired magnetism, in the hard iron or in the steel. This cause has been attributed by some to the action of a coercive force, which results either from a new arrangement of the molecules of the hard iron and steel, or from the interposition of the molecules of some other body; such, for instance, as we understand by that vague term, the *magnetic fluid*. We shall, however, return to this subject at the end of the present Section.

35. We must warn the reader, that the separate existence, or, indeed, the existence of any magnetic fluid at all, remains to be proved. We are by no means sure that electricity has an existence apart from matter; it may be, (as heat and light are thought to be,) merely a state or property of matter, and consequently not existing in an isolated condition. Many scientific terms, which have been adopted from very ignorance,—from a loss what term to apply to the hidden causes or motive power producing certain obvious and important effects,—have been adopted, which at first view appear absurd. Thus,—heat, light, and electricity, are termed "imponderable fluids," which is a

manifest contradiction of terms: since a fluid is, and must be, material, and one of the most obvious properties of all matter, is *weight*. Again, space is said to be filled with a rare and subtle fluid or ether, whose vibrations produce light. Space, in the geometrical meaning of the term, is bounded by lines or sides, and is therefore sufficiently comprehensible; but we allude to the metaphysical interpretation of the term *space*, by which is meant a place absolutely void and unoccupied by matter; and yet this perfect vacuity is said to be *filled* with ether! Many other examples might be adduced; but these will suffice to caution the student not to attach certain determinate ideas to terms which he will frequently meet with in science,—which have been invented for convenience only,—and which will probably be discarded and forgotten as the boundaries of science become enlarged.

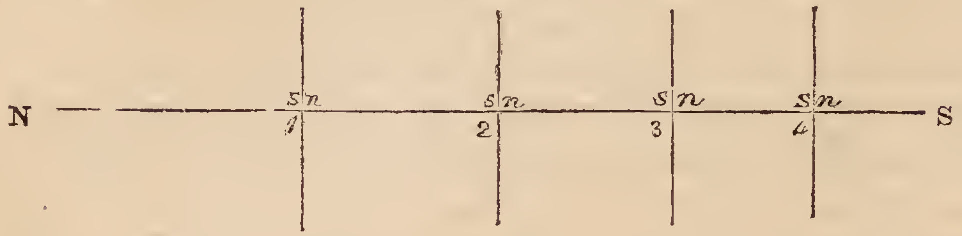
36. We have said that hard iron or steel acquires permanent magnetism very slowly, by mere contact with a magnet; but it becomes permanently magnetic almost instantaneously if it be rubbed in the direction of its length several times,—not backwards and forwards,—but forwards only.

37. A very good method of magnetising a steel needle or a piece of steel wire (knitting-needles are well adapted to the purpose), is to place the needle upon a flat surface, and holding a bar-magnet in each hand, to join the opposite poles at the centre of the wire,—inclining the magnets upwards so that each magnet may form, with the needle, an angle of about 15° or 20°. Pressing upon the centre of the wire with one magnet, move the other slowly along to the end of the wire, and to a considerable distance beyond it. Then, by a wide circuit of the arm, bring the magnet into its former position; press it upon the wire, as before, and then urge along the other magnet in a contrary direction, and proceed with it in the same manner; and so on several times, observing to give an equal number of strokes with each magnet. In this way the steel wire will be found to have acquired a considerable share of permanent magnetism; and its poles will be found to be the reverse of those, which were respectively applied to it, in using the bar-magnets.

38. By means of this wire, another remarkable property of the magnet can be exhibited. Let N S, fig. 9, represent the wire of steel magnetised as above, and let it be divided into five unequal parts. In its whole or perfect state N is supposed to represent the north, and S the south pole. In its broken state the fragments are each and every one no less perfect magnets than the wire, before it was so divided. The points of division

1, 2, 3, 4, separate two poles: thus, in the figure the five fragments become five perfect magnets, whose poles are N *s* 1,

Fig. 9.



n s 2, *n s* 3, *n s* 4, and *n* S 5. And if we suppose a subdivision of the wire to proceed to such an extent that each part consisted of a single atom only, we should arrive at a similar conclusion (only by an inverse method), to that which we detailed as connected with figure 7.

39. If a steel ring be magnetised, the magnetic properties remain concealed while the ring is whole; but if it be broken at any points, each fragment will be found to possess the properties of a common magnet.

40. Soft iron becomes magnetic by being subjected to various processes, whose effect is to alter the position of equilibrium of the particles which compose it. If a piece of iron or steel be struck with a hammer so as to cause a ringing, vibratory motion among its parts, it will be found that this alone is sufficient to induce permanent magnetism. A common poker and a hammer are sufficient to show the effect of a decided attraction and repulsion upon the needle in fig. 1. When the effect has been produced upon this bar of metal, if it be reversed and struck on the other end, the poles will be reversed; and in every case the lower end of the bar assumes northern polarity.

41. By passing a powerful electric shock through a piece of steel, it is rendered permanently magnetic. This experiment has been often cited as proof of the identity of the electric and magnetic fluids; but this is an incautious deduction, since there is no doubt, that the effect of the electric shock upon the steel is merely mechanical, producing the same effect as the hammer in the last experiment. This conclusion, respecting the merely mechanical effects of the electric shock, has been arrived at by students of magnetism from witnessing the irregular and contrary effects produced, under similar circumstances, upon metals proposed to be magnetised in this way.

42. If a bar of steel or iron be made red hot, and placed in the direction of the north and south magnetic poles, and so

allowed to cool,—it will become a permanent magnet. A bar or horse-shoe of steel can be magnetised to saturation by heating it to redness, and while under the influence of a strong magnet placed near, quenching it suddenly with cold water.

43. Magnets are formed in various ways, and many of them by the spontaneous action of the earth. The poker mentioned above becomes a magnet immediately, when placed on the ground parallel with the dipping-needle;—that is to say, in a line with the magnetic north and south, and at about 20° from the vertical. But this magnetism is transient, and is lost by change of position. It is however rendered more stable, as was said, by percussion, if this be done in the posture described. We have also often found that at the end of summer the steel fire-irons, which had remained for several months resting on the fender in a room, had become decidedly magnetic. Iron window-bars, if their direction and that of the magnetic meridian be similar, also become magnetic. So also does iron wire, when twisted and broken into pieces. And a steel sewing-needle becomes also magnetic by exposure to the violet rays of the spectrum. The last method was successfully repeated by the writer during the summer of 1837. It was originally announced by Morichini at Rome, and in England by Mrs. Somerville, a lady who does honour to her country. She has afforded to her countrywomen a bright example, that high scientific attainments need not be confined to one sex in particular; and that they are not incompatible with those other qualities which peculiarly adorn the female mind.

44. It is a remarkable circumstance, that the very causes which induce magnetism in other bodies, are also most active in effecting its destruction. Thus, if a magnet be struck, or heated to redness, the magnetising force is either very much impaired, or altogether destroyed. At a high temperature, magnetised bars of steel lose all their power, and become insensible to the action of magnets. It is necessary, therefore, to exercise some caution in the use of magnets, so as to save them from blows or falls. They ought also to be carefully preserved from rust; and this may, in great measure, be ensured by gently warming them and covering the whole of their surface (except the poles and about an inch from the poles,) with sealing-wax, dissolved in spirits of wine. As the spirit evaporates, a permanent and uniform coating of resin remains upon the surface of the magnet. When the magnets are not in use, the parts not covered with resin may be preserved from rust by a paste prepared in the following manner:—In a Florence flask with the

neck cut off, heat about two fluid ounces of olive-oil to about 400°. This will expel any water which may be mechanically combined with the oil. Then stir up with the oil, a quantity of newly made dry lime, sufficient to form a soft paste. If the exposed parts of magnets be anointed with a thin surface of this paste, they will be effectually preserved from rust. When the magnets are to be used, this paste can be wiped off easily. In this way the writer preserves his magnets, and can speak from experience of the success and advantage of the plan.

Boiling water has been found to be very injurious to a magnet; but, as the magnet cools, its power returns. At 200° of heat, two-fifths of the magnetism is dissipated; and at 500° it is all lost. These effects are likewise accelerated, when the magnet lies oblique to the meridian, or with its poles reversed.

45. The application of a force to a magnet which has the effect, as we have said, of magnetising a bar of steel, and of destroying such magnetism when already formed, operates sometimes in reversing the poles of a magnet. Thus, an electric discharge may convert a steel needle into a magnet;—may destroy a magnet already formed;—or may reverse its poles. The latter effect has been the cause of many a shipwreck. We read some time ago of a Genoese ship sailing for Marseilles, which was struck by lightning at a short distance from Algiers, when the electric discharge reversed the poles of the compass-needle; so that the ship dashed on the African coast, when it was thought on board that they were sailing to the north.

46. We should observe, before quitting this part of our subject, that Professor Robison, who, in the middle of the last century, made many and varied experiments on this occult branch of science, suspended by a thread a very fine artificial magnet, with its south pole pointing downwards. A person was employed to tap it incessantly with a smooth pebble, in such a manner as to make it ring very clearly. Its magnetism was examined from time to time, with a very small compass-needle. In three quarters of an hour its original magnetism was destroyed; and the lower end showed signs of a north pole. The same magnet was re-magnetised, and made as strongly magnetic as before; it was then tightly bound over with wetted whipcord, leaving a small part bare in the middle. It was again tapped with the pebble, but could no longer ring. At the end of three quarters of an hour, its magnetism was still vigorous, and was not gone after two hours and a quarter. Professor Robison supposes that sonorous percussion produces a recession of the particles of a magnet; and that at every such recession a certain

portion of the magnetic fluid escapes and is lost. Percussion and friction, in the required position, would seem, therefore, from all that has been said before, to be the chief means of magnetising iron and steel. These means do, as it were, waken up the inert particles of the metal to admit new magnetism, or to develope that which already resides in it, originally derived from the earth.

47. Horse-shoe magnets are sometimes combined in the number of six or eight, forming what is termed a magnetic battery. They very much improve by being kept suspended and loaded as in fig. 3. If, for example, a magnet will bear up exactly ten pounds, and no more, and we suspend it with this weight attached for a week or two, we shall probably find, that at the end of that time it will sustain ten and a half pounds; and so on, with a gradual increase. It is probable, however, that this attractive force is subject to a diurnal and annual variation; that is to say, the magnet, when it has attained its maximum of attractive power, will support a greater weight at one time of the day than at another; and at one season of the year than at another.

48. Iron and steel are not the only bodies capable of exhibiting magnetic properties. That their power in this respect infinitely exceeds that of all other bodies, is certain; and this has probably led to the monopoly so long attributed to them. Nickel and cobalt, formed into needles, exhibit polarity. Antimony and bismuth have been observed to repel the needle when carefully suspended. Other metals affect the magnetic needle more or less. And here we must notice an important distinction: a body may be magnetised so as to act upon the magnetic needle, and be attracted by it, at any point of its surface indifferently, without exhibiting any repulsive property; whereas, if a body possess polarity, a point of its surface which attracts one pole of the needle necessarily repels the other.

49. We ought to remark that most substances in nature may be made to exhibit traces of magnetism. Various minerals, and animal and vegetable substances, have been seen to be affected by the magnet: but before a judicious opinion can be formed on these heads, it should be carefully considered to what extent iron may be proved to exist more or less in the substances in question.

50. v. Variation. The variation or declination of the needle, is a peculiarity of the magnet of very great importance to our present subject, and we proceed to give the reader as full

an account of it as our limits, and the popular character of this work, will allow.

We have said, that when a needle is suspended, free to move in a horizontal plane, its north pole points towards the north, and its south pole towards the south; and that, if disturbed from this position, it will regain it after a series of oscillations on either side of its axis or line of direction. Now the needle does not in this country point to the true north, or to the north pole of the earth, but to a point about 24° to the west of the true north; and this deviation from the north is called the *variation** of the needle or the magnetic *declination*, to distinguish it from the true geographical meridian from which it differs. A vertical plane, passing through the direction of the needle at any particular place on the earth's surface, is called the *magnetic meridian* of that place, which thus of course differs from the true or geographical meridian; and this difference is greater at some places on the earth's surface than at others; but there are a few points on the earth's surface where the magnetic and the true meridian coincide.

51. The places on the Earth's surface where there is no variation, are situated on a line which may be supposed to encompass the globe; this is called the *line of no variation.* This line we may consider to be divided into two parts, the western, or that situated in the western hemisphere; and the eastern, or that situated in the eastern hemisphere. The western line of no variation, as marked in Professor Barlow's valuable Chart of Magnetic Curves, begins in latitude 60° N. to the west of Hudson's Bay; whence it proceeds in a south-east direction through the Canadian lakes. After passing through part of the United States it reaches the South Atlantic Ocean, touching in its course the north-eastern point of South America, near Cape Saint Roque; until it reaches towards the South Pole, where it is lost. The eastern line of no variation begins in the latitude 60° S., to the south of Van Dieman's Land, and, passing across the western part of Australia, describes

* It is not known when the variation of the needle from the true north and south was first observed; but it seems natural that the fact of the variation must very soon have struck those who knew the properties of the load-stone, and the tendency of a magnetised needle, when poised, to point in a certain direction. It seems to be agreed that the Chinese were in the habit of allowing for variation many ages ago. Sebastian Cabot first observed, in the year 1497, that the variation was the same to all needles at the same place. It was also generally thought to have been the same at the same places in all ages; but Mr. Gellibrand, in 1625, pointed out the change in the variation.

a considerable curve in the Indian Archipelago. Here it is supposed to divide into two branches; one of which crosses the Indian Sea and enters Asia at the southern point of Hindustan, which it traverses, together with Persia, and passing through the west of Siberia, stretches to Lapland and the Northern Sea. The other branch proceeds by a more direct northern course,—crossing China and Chinese Tartary,—and quits Asia to the east of Siberia, where it is lost in the Northern Arctic Ocean.

52. It will, therefore, be understood that the magnetic needle points to the true north at any one of the places through which the line of no variation passes.

53. It is remarkable that Columbus noticed this variation of the needle for the first time, when sailing across the Atlantic Ocean in his attempt to find a new world. It was on the 13th of September, 1492, and he was perhaps 200 leagues from land. We are told, and by inference from the following table we might conclude, that the variation was at that time a little to the west at London. It appears that Columbus noticed the variation to be as much as half a point; or between five and six degrees. It is not improbable that he himself had been aware of it before; but that his pilots and mariners noticed it then particularly for the first time, having leisure on the wide ocean during many weeks, for anxiety and curious alarm. It seems that Columbus was prepared with a theory to account for this deviation of the laws of Nature,—as the terrified sailors deemed it to be. The needle was not at fault, he said, for it did not tend to the polar star, but to a fixed and unseen point; and that the apparent irregularity in the direction of the needle, was owing to the movement of the polar star, which constantly described a circle round the pole. This explanation, we see, is partially correct; and we admire the perspicacity of the man, who, with so little means, could trace up so fearful an effect to a cause founded partly in truth. But to return:—

54. It is important and remarkable to observe, that the variation of the needle is itself subject to variation:—That is, the difference between the magnetic and the true meridian has not always been the same. We have stated that the needle in this country points about 24° to the west of true north. During the sixteenth century and a great part of the seventeenth, the variation at London was easterly: before which time it was probably to the west. The Chinese had observed a westerly variation of the North pole or rather an easterly variation of the South pole of the needle, 400 years before Columbus, as we learn from Humboldt; but the changing nature of this variation is dependent

on the continual shifting of the magnetic lines. It is clear, then, that the declination of the needle must have been observed before the time of Columbus by those who used it at all; although the changing nature of this declination might not till his time have occupied the attention of any. The following table will show the variation at London, at the different periods as here set down.

Year.	Variation.
1576 . .	11° 15′ East.
1580 . .	11° 17′ maximum of easterly variation.
1622 . .	6° 12′
1634 . .	4° 5′
1657	No variation—that is, the magnetic meridian and the true meridian were coincident.
1666 . .	0° 34′ West.
1670 . .	2° 6′
1700 . .	9° 40′
1760 . .	19° 30′
1800 . .	24° 2′
1813 . .	24° 20′ 17″
1815 . .	24° 27′ 18″ maximum of westerly variation.
1816 . .	24° 17′ 9″
1820 . .	24° 11′ 7″
1823 . .	24° 9′ 40″
1831 . .	24°

A writer in the *Magazine of Popular Science*, vol. iii. p. 234, says, that on the 14th December, 1836, the variation was 23° 37′ 30″ west.

At Paris, there was no variation in 1669. In 1829, the variation was 22° 12′ 5″ to the west.

55. We should here observe that this variation of the variation of the needle, first particularly noticed in the sixteenth century, ever has been, and still is, constantly going on, though not with an uniform angular motion. Major Sabine first announced and proved to the world in 1822, that the needle had attained its maximum western declination at London in 1816; and that it was then, in 1822, in a course of retirement back upon the north.

56. The needle is also subject to menstrual and diurnal variations, which we may briefly notice.

Between the months of January and April, the magnetic needle recedes from the north pole of the globe, and its western declination is increased. But from April to the beginning of July, the declination diminishes; that is, the needle approaches towards the true meridian.

From July to October, the needle returns towards the west;

and in October it occupies nearly the same position as in May. Between October and March the motion towards the west is smaller than in the three preceding months.

So that, during the three months between the vernal Equinox and the summer Solstice, the needle retrogrades towards the east; and during the following nine months, its motion is towards the west.

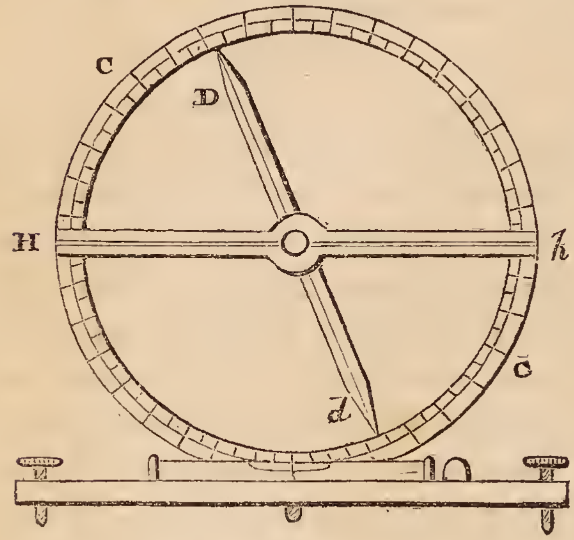
57. The general results of numerous observations of the diurnal variation may be briefly stated thus:—The deviation of the needle from its mean position, is easterly during the forenoon, and greatest at about eight o'clock; thence returning quickly to its mean position, which it attains between nine and ten o'clock; after which it becomes westerly; at first increasing rapidly so as to attain its maximum at about one o'clock P.M., and then slowly decreasing during the rest of the day, and arriving at its mean position by about ten o'clock at night. But it is now generally considered that this diurnal variation, (which was first noticed in the year 1724,) is due to the effects of the solar heat, which tends to lessen the attractive power of magnets. When the sun is eastward of the needle, the attractive force to the east is diminished, and consequently the needle is drawn westward; and when the sun gets to the west of the needle, it is drawn eastward. This consideration will help to elucidate the statements before made; that the diurnal motion of the needle is westward in the fore part of the day, eastward in the latter part, and that it is stationary at night, as announced by Mr. Graham, who first began to observe these effects; and furthermore, that it is twice as great at the summer, as at the winter, Solstice.

58. The amount of the menstrual and diurnal variations is exceedingly small, and requires very accurate and delicate instruments to detect it. From some observations made at Paris, it appears that the diurnal variation never exceeded 25′, while on some days it amounted to no more than 5′ or 6′. It has been noticed also, that it increases from the Equator to the Poles.

59.—vi. DIP. We have hitherto considered the properties of the magnetic needle in its motion through a horizontal plane, by reference to fig. 1, where the needle is so poised as to admit of that motion only. If, however, a needle of steel be formed with an axis passing through its centre at right angles to the axis of the magnet, and so suspended as to allow of its motion in a vertical plane, we shall arrive at some very important information respecting the action of the earth upon the

magnetic needle so poised. The dip of the needle was first noticed in the year 1576. Figure 10, represents the simplest construction of the apparatus necessary for this inquiry.

Fig. 10.



60. Here it will be seen that the needle is no longer horizontal, but declines from the plane of the horizon, so as to make, with a vertical plumb-line, an angle of about 20°. This divergence of the needle from the horizontal plane is therefore about 70° and is called its *dip;* and the apparatus represented by fig. 10, is called *a dipping-needle.* It consists of a needle, D *d*, formed of a flat piece of steel, pointed at the ends. A small cylindrical axis passes at right angles through its centre, moving freely in circular holes, made in the horizontal bars, H *h*, which form the diameters of a graduated circle, C *c*, by which the angle made by the needle with the horizon, is determined. This circle is fixed on a stand provided with adjusting screws and two spirit-levels, in order to ensure a horizontal position. To make an observation, it is usual to ascertain the direction of the magnetic meridian by means of the needle in fig. 1, and then to move the dipping-needle to such a distance that it may not be affected by the horizontal needle. The graduated circle is now adjusted in the plane of the magnetic meridian, and rendered accurately level. In this way the dip will be found to be at London 69° 47′.

61. Far more complicated and delicate apparatus has been contrived in order to determine the dip of the needle. This we need not stop to describe :—the great object of the reader should be to become thoroughly versed in the principle of an instrument; and this will be of much more value than the most perfect knowledge of apparatus, which, in its most finished and complicated state, is necessarily confined to those few accurate observers, whose results we are accustomed to receive with all the confidence which pure truth inspires, and to apply practicably to use.

62. The dip of the needle, like its variation, is different in different parts of the world, and is various at various times.

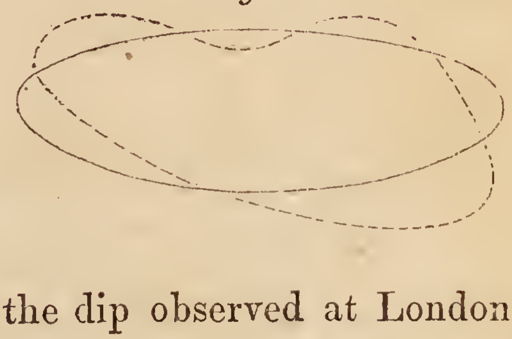
If we suppose a traveller situated at the north magnetic pole,

and furnished with a dipping-needle, it would, at that spot, form an angle of 90° with the horizon; it would in fact be erect; its north pole pointing downwards:—(More properly speaking its SOUTH Pole; the *north* pole being misnamed, as we showed before, 20.) So that the north magnetic pole of the earth attracts to itself the real south pole of the dipping-needle. If the traveller progressed in a straight line from the magnetic north to the equator, the needle would form an angle, constantly becoming more acute with the horizon; until having arrived at the equator, the needle would be so balanced between two equal forces as to be perfectly horizontal. If, now, he cross the equator, and proceed towards the south magnetic pole, the south * end of the magnet will dip; which dip will increase, until, having arrived at the south magnetic pole, it will be erect, and will describe an angle of 90° with the horizon.

63. This fact may be well illustrated by placing a long bar-magnet flat on a table, and a small dipping-needle on the north pole. The south end of the needle will point downwards, describing with the magnet an angle at 90°. If the needle be moved gently along the surface of the magnet, it will get more horizontal as it approaches the centre; when it will become quite so. Passing this centre the north pole begins to dip, and at the south end of the magnet the north pole of the needle will be erect. This experiment will truly illustrate the incorrectness of the names which have been vulgarly given to the poles of a magnet, if this be compared with the former paragraph.

64. Those places on the surface of the earth where there is no dip, are situated in an irregular line near the true equator, which it cuts four times. This line is called the *magnetic equator*, and is represented by the dotted line in Fig. 11 †.

Fig. 11.



65. The dip of the needle is subject to a constant change,—increasing in some places, and diminishing in others. The following table shows the changes of the dip observed at London, since 1720.

* Popularly speaking—but, as we showed before, it will be, in truth the *north* end of the dipping-needle.

† In this figure, the magnetic equator appears to cut the equator of the earth *six* times: this, however, is only a necessary effect of representing the lines in perspective.

Year.	Dip.	Year.	Dip.
1720	74° 42′	1818	70° 34′
1773	72 19	1821	70 3
1780	72 8	1828	69 47
1790	71 53	1830	69 38
1800	70 35		

66. The retrograde variation of the dip of the needle at London is a consequence of the change of magnetic latitude, arising from the motion of the nodes of the magnetic equator; that is, the change in place of those points where the magnetic cuts the true equator:—and the same principle has been applied to explain this variation of the dip in different parts of the world.

67. There is also an annual and diurnal variation in the dip. It has been found to be 15′ greater during summer than during winter; and about 4′ or 5′ greater before than after noon.

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68. We have thus pointed out the most general and important properties of the magnet. Before we conclude this section, it is our duty to notice a few important problems connected with terrestrial magnetism. This can only be done imperfectly and briefly in this place. We must therefore refer such of our readers as desire further information to the admirable works of some of our first magneticians, who have, within the present century, so much extended the bounds of this admirable science.

69. From what we have already written, the reader will easily gather, that the intensity with which the earth's magnetism acts upon the magnetic needle, varies at different parts of the surface of the globe. The method of determining the intensity of terrestrial magnetism is as follows:—If a needle be delicately suspended by means of a single fibre of silk, and, when at rest, be disturbed from its position of repose, it will regain that position by a number of oscillations. Now, supposing the north and south polar magnetism to be equal and equally distributed, the magnetism of the earth acts with equal force upon either half of the needle, and both these forces contribute to draw the needle into the magnetic meridian; and the greater the force, the more quickly will the needle vibrate and recover its first position. Now a comparison of the number of oscillations, performed by the same needle at different spots on the earth's surface, gives the law of magnetic intensity; which, like nearly every known force that proceeds from a centre, follows the inverse ratio of the square of the distance. The needle, therefore, may be considered in the light of the pen-

dulum, which, vibrating by the action of gravity, will give a greater number of beats at London within a given time than at the equator; the latter being farther from the earth's centre than the former, and more influenced by centrifugal force. In like manner, the intensity of the magnetic force diminishes in proportion to the square of the number of oscillations made by a magnetic needle within a given time, at different distances from the chief source of magnetism; say, either of the earth's magnetic poles.

70. For example, let a needle vibrate round the line of its dip in the plane of the magnetic meridian, and suppose the number of vibrations per minute is 22 at one place on the earth's surface and 27 at another place: then the intensity of the magnetic force at these places is as 22^2 to 27^2. We will suppose the first place to be somewhere on the magnetic equator, and we will call the intensity of the magnetic force at that place 1. Then we shall find that as $22^2 = 484$ is to 1, so is $27^2 = 729$ to 1·5, the intensity of magnetic force at the second place, situated somewhere between the magnetic equator and a magnetic pole.

71. Humboldt found that the same dipping-needle, which made 245 oscillations or vibrations at Paris in ten minutes, made but 211 at Peru in the same time. The latitude of Paris is $48\frac{3}{4}°$ N.; and Peru lies between 5° and 20° S. If the intensity of the magnetic force at Paris be set down as 1, then that at Peru must be regarded as being ·7417. Hence is derived a general law;—that the number of oscillations decreases in approaching the magnetic equator, and increases in approaching the magnetic poles. It was moreover proved, in the case just cited, that the difference in the number of vibrations at Peru, as compared with Paris, could not be ascribed to a diminution of magnetic force in the compass, nor to the effects of heat, or of time.

72. Local causes frequently produce irregular results. Biot, in the summer of 1804, found that his needle had a stronger tendency to seek the magnetic meridian when carried to the Alps, than it had at Paris before his departure, or after his return. This needle, which, at Paris, made 83·9 oscillations in ten minutes, gave oscillations, in the same time, as follows, at these places:—Turin 87·2; on Mount Genêvre 88·2; Grenoble 87·4; Lyons 87·3; Geneva 86·5; Dijon 84·5. The action of the Alps has, then, a perceptible influence on the intensity of the magnetic force. Humboldt noticed the same at Perpignan, at the bottom of the Pyrenées. It is considered that this superior

magnetic action is due to the mass of these mountains, or to the ferruginous matters contained therein.

The intensity, therefore, of the earth's magnetism is found by operating in this way at various parts of the earth's surface.

73. Like all the elements of terrestrial magnetism, the intensity is subject to variation. Thus, Captain Parry noticed an increase of the magnetic intensity at Port Bowen from the morning to the afternoon, and a diminution of it from the afternoon till the morning. It has also been discovered that the magnetic intensity is generally at its minimum between ten and eleven o'clock A. M., when the sun is about on the magnetic meridian; and that it increases until about nine or ten o'clock P. M., after which it decreases, and continues to decrease until ten or eleven o'clock in the morning.

The magnetic intensity is also subject to a monthly variation; it being at its maximum in December, and at its minimum in June.

74. The whole of the phenomena of the magnet, as we have thus briefly developed them, varying as they do at different parts of the earth's surface,—at different seasons of the year,—and at different hours of the day,—must depend upon some force which is itself also subject to variation, and which is resident in the earth. This appears to be an almost irresistible conclusion; and, accordingly, at very early periods of magnetic science, various hypotheses were framed, all of which had relation to the earth, as the cause of magnetic phenomena: which Dr. Knight conceives to have been originally magnetised by a shock entering below the southern tropical line. It is not our intention to discuss these theories; since to do them justice would occupy too much of our space; and the utility of bringing them, at any length, before the reader's notice, may be questionable. We may merely remark, that the most reasonable theory of by-gone philosophers is that of Halley; who regarded the globe as a great magnet having four poles; two to the north and two to the south, at considerable and unequal distances from the poles of the earth. Two of these poles, that is, a north and a south pole, are supposed to be fixed; the other two moveable. More recently a similar hypothesis has been adopted by Hansteen; who refers all magnetic phenomena to such causes.

75. But the *theory* of magnetism, so far as relates to observed magnetic phenomena, is a simple and elegant specimen of inductive reasoning. We have already (33) referred the existence of the two opposite magnetic forces to two contrary fluids, one of which predominates in one pole, and the other in the

other pole. It follows therefore, on this assumption, that in all magnets the poles of the same name will have the same predominating fluid; and as these are mutually repulsive, it is concluded that each fluid repels itself: also that, as poles of contrary names possess different fluids, and as these poles attract each other, it is concluded that one of the fluids attracts the other. There is also a tendency in the two fluids to re-combine; and they can only be kept separate by a peculiar molecular constitution of matter, of which we are ignorant; although it must exist in steel, for example, which is capable of what we call *permanent* magnetism, while it cannot exist in soft iron, and other bodies, which can only be magnetised temporarily. Now there is good reason for supposing that soft iron really contains the two magnetic fluids; but that they are combined, and neutralize each other: that the action of a magnet is to decompose this combination—that is to say, the magnet attracts one fluid and repels the other; so that the fluids are separated in such a manner that the fluid of one kind is accumulated at one end; and the fluid of the other kind at the other end; the nature of the fluid at either end being determined by the particular pole of the magnet to which the iron is attached. It is not improbable that the magnetic fluid is similarly combined in a large variety of bodies; but that, in consequence of some peculiar molecular constitution, we have not yet obtained the means of effecting a decomposition of such combination, either by contact with the magnet, or by other means; except in a few cases already referred to (48).

76. The action of the magnet upon iron and steel can thus be conceived to be infinitely exerted without any loss to itself. One magnet is sufficient to magnetise thousands and tens of thousands of steel or iron bars, without any loss to itself of magnetic power. A piece of soft iron by contact with a magnet loses nothing, and gains nothing: nor does a piece of unmagnetised steel:—but the difference between them is striking. If we suppose the combined magnetic fluids to be *de*composed only when under the influence of the magnet, and to be *re*composed the moment such influence is withdrawn; we must suppose that, in the case of steel, no such recomposition occurs; and that, in the numerous cases in which magnets are said to be destroyed, nothing more occurs than the recomposition of the two fluids.

Section II.—The Compass.

77. The term *Compass* is applied to all instruments whose purport is to ascertain the position of the magnetic meridian, or of objects with respect to that meridian; and when referred to the true meridian, this position is called the *bearing* of such objects. The compass is employed by land, as well as by sea; and constitutes one of the most extensively useful instruments that science ever bestowed on man.

78. Compasses may be divided into two kinds; first, those which merely indicate the magnetic meridian. Such are called the *land-compass*, the *mariner's* or *steering-compass*, and the *variation-compass*. Secondly:—Those which mark the angular distances of objects from the magnetic meridian. Such are called *azimuth-compasses*.

79. A great deal of discussion has been carried on at various times, respecting the origin and antiquity of the compass. It was thought that Marco Polo, the Venetian, brought the knowledge of it into Europe, from China, in the year 1269: but it certainly does not seem to have attracted general notice among the mariners of Europe, until the beginning of the fourteenth century; when one Flavio Gioja, a Neapolitan sailor, ventured to use it on the seas, and was thus erroneously styled the inventor of it. There is some authority for the opinion that the Chinese, Japanese, and Arabians, had been in the habit of using this instrument for directing their course by land. The Chinese, we are told, made the needle float on a piece of cork, and thus used it in their shipping at the time of the Christian era; as also the East Indians generally, who, in the sixteenth century and prior to that time, suspended the magnetic needle on a point in a china dish filled with water, so that the needle gently floated: the bottom of the dish being marked with cross lines to denote the principal winds. The Syrian captains are said to have used a similar method for guiding their vessels in dark nights; and, as early as the thirteenth century, they magnetised the needle with a load-stone, and stuck it into a piece of wood to make it float, and thus they found the north. The Jesuits, who journeyed eastward at the beginning of the seventeenth century, relate many and curious things on this head. At any rate the instrument was, it seems, undoubtedly known in Europe, as a scientific curiosity, early in the twelfth century; though its practical worth was not tested by the regular seaman until two centuries after, when the Spanish navigators were found to employ it with confidence and success.

80. The essential parts of the compass are; *first*, a magnetised needle, having a cap in its centre for the reception of a sharp point or pivot, fixed in the middle of the base of the instrument. *Secondly;* A circular card, divided into thirty-two equal parts by lines drawn from the centre to the circumference. *Thirdly;* A box, (square or circular), but covered with a disk of glass, called the *compass-box*, to contain the needle and the card, in order to protect them from dust, and from the agitation which might be produced by wind. These various and essential constituents of the compass we proceed to detail.

81. i. THE NEEDLE. The best form and construction of compass-needles is a point of first-rate importance, and has been determined by taking advantage of all the resources which modern science affords. Our information on this subject is derived chiefly from the valuable researches of the late Captain Kater.

82. It was found that the best material for the construction of the needle was shear steel: this received a greater magnetic power than blister or spur steel. Needles of cast steel were very inferior; because, owing to their extreme hardness, they are not so susceptible of magnetism. If, however, such needles be employed, their temper should not be greater than the blue colour.

83. It was also found, that the hardening of a needle throughout its length, very much diminished its capacity for magnetism. A needle, which was soft in the middle, and its extremities hardened at a red heat, afforded the greatest directive force.

84. Polishing the steel needle did not seem to affect its capacity for magnetism; and in magnetising it by rubbing it with a bar-magnet, (as already described,) a gentle pressure was found quite as efficacious, if not more so, as hard rubbing.

85. It is important that the polarities of the compass-needle should be concentrated as much as possible at the two ends, in order that the needle may be the more alert in its indications; the north pole of the needle being stronger in north magnetic latitude, owing to its proximity to the north magnetic pole, and the south pole of the needle being stronger to the south of the magnetic equator for a corresponding reason. It is also desirable that its length should not exceed five inches. A greater length than this affords the chance of the existence of several consecutive poles, which greatly diminish the directive force. So that very hard short needles are preferable to long ones.

86. As the directive force of the needle is but little influenced by the extent of its surface, but depends upon its

mass when saturated with magnetism, it becomes a point of great importance to ascertain the best form for the compass-needle. The most common forms, (guided however in their construction by no scientific principle,) are the cylindric, the prismatic, the rhombus, and the flat bar, tapering like an arrow at the poles. Coulomb, a magnetician of first-rate ability, however, preferred the last of these forms; but, whatever be the form of the needle, he has found that any expansion at its ends is attended with loss of power. The two forms recommended by Captain Kater are shown in figures 12 and 13; the first having the form of a long ellipse five inches long and half an inch wide, with a pierced cross piece for the purpose of suspension. But of all forms, Captain Kater preferred that of the pierced rhombus, as shown in fig. 13. These needles were made of shear steel, and their weight varied from 45 to 66 grains. The mariner's compass, however, as improved by Dr. Knight in the last century, has the needle long, quite straight, and squared at the ends. Before the time of Dr. Knight, this instrument was in a very rude state.

Fig. 12.

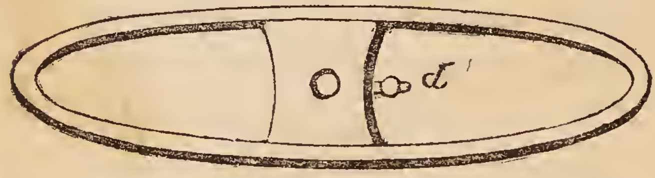
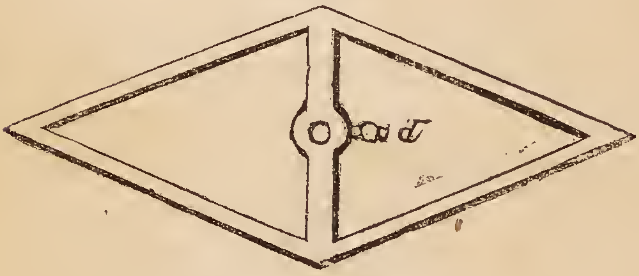
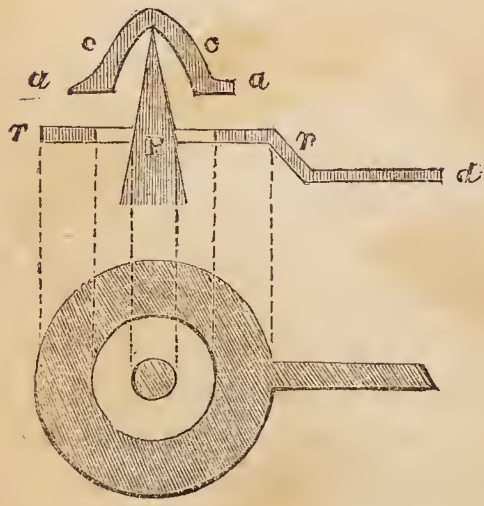


Fig. 13.



87. The mode of suspension of the needle is shown in fig. 14*. A hollow cap *c c*, about a quarter of an inch in diameter, is formed of agate or garnet, and carefully hollowed. This cap is fitted into a hole left in the cross piece of the magnet *a a* as shown in the last figure. The interior apex of the hollowed cap rests upon a pivot *p*, the point of which forms an angle of from about 15° to 20°. There is also a ring *r r*, to lift up the cap of the needle from off the pivot,

Fig. 14.



* It is not known who first suspended the needle *horizontally;* but it is believed to be of great antiquity.

when not in use. This ring is connected with a rod or handle *d*, which is continued to the outside of the compass-box; where it can be set in motion; so as to displace or replace the needle, as may be required. In the figure two views of the ring and handle are given; a front and a side view; the dotted lines serving to connect the corresponding parts in the two views.

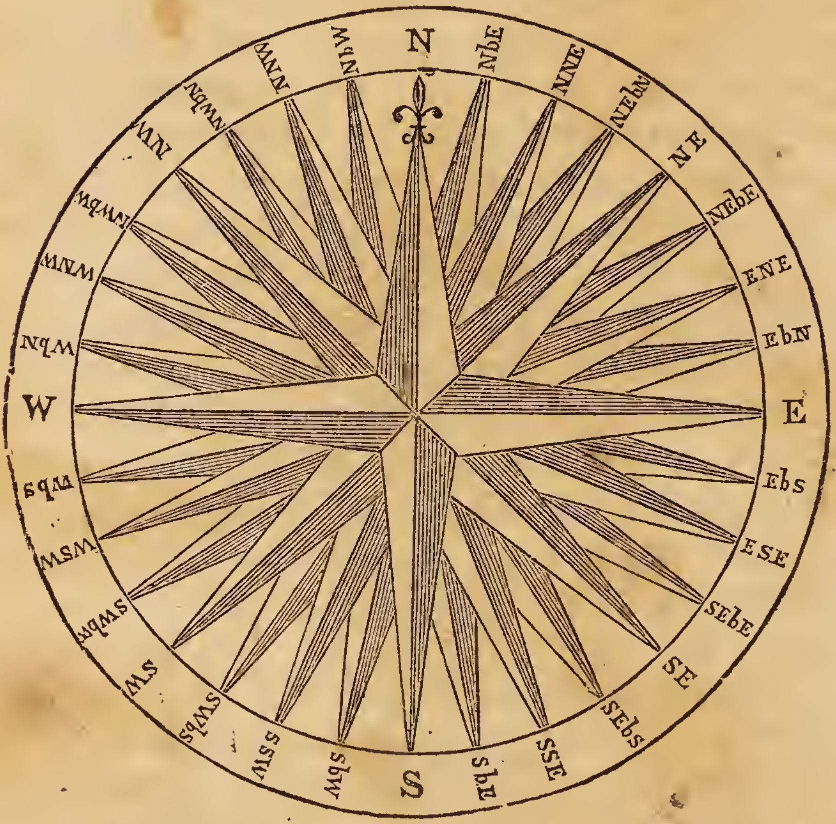
88. As we have seen from the phenomena of the dip, that a nicely suspended magnetic needle always tends to place itself parallel with the magnetic axis of the globe, it follows, that the needle suspended on a fine point, is never (except at the magnetic equator,) in a perfectly horizontal position; but, in the northern hemisphere, that end which we call the *north* is depressed, and the south end proportionably elevated. To counteract this tendency to dip, a small weight is sometimes attached to the needle on the southern side of its central part, as shown at *a* in figures 12 and 13, by which means horizontality is attained. But, as the force which draws the needle from its horizontal position varies at different parts of the earth's surface, so must the counteracting force vary. This is accomplished by means of a sliding knob *a a*, figures 12 and 13, which acts with various degrees of force according as it is near to, or removed from, the centre of the needle;—its counteracting force being, of course, greatest at the extremity of the rod upon which it slides.

89. ii. CARD. We pass on now to a description of the second element of the compass, namely, the card; as shown in fig. 15.

This card may be regarded as an artificial representation of the horizon of any place. Its form is circular, and it is divided into thirty-two equal parts, by lines drawn from the centre to the circumference; which are called *rhumb*-lines, the extremities of which are called *points* or *rhumbs:*—the intermediate spaces are subdivided into halves and quarters, called *half-points* and *quarter-points*. The whole circumference is likewise divided into 360°. The angle, therefore, included between any two rhumbs, amounts to 11° 15′. The principal points are four, called the four *cardinal* points; as being those on which all the others *hinge*, or depend. The north point is ornamented with a fleur-de-lis, for the sake of more ready observation. This ornament was first placed at the north cardinal point by some European nation, which distinguished itself in maritime research during the middle ages. Some refer it to the French; others to the Neapolitans. Opposite this is the south point; and looking towards the north, the east point is on the right hand, and the west point on the left. The intermediate points are compounds

of the four cardinal points, and are situated in the order shown in fig. 15, as named originally by the Dutch.

Fig. 15.



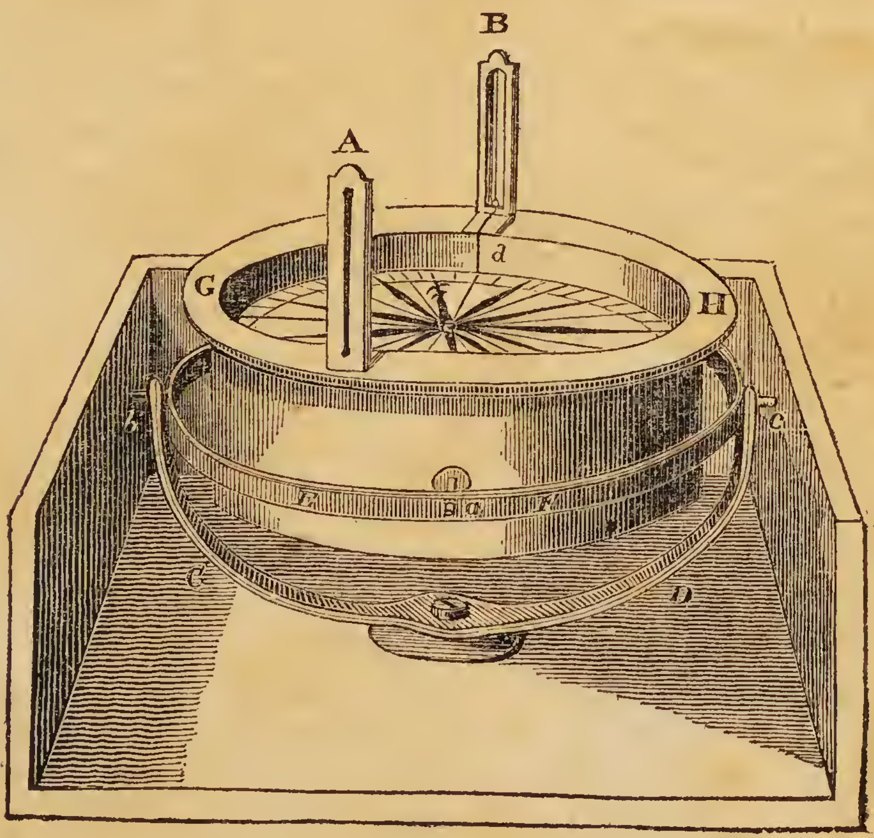
90. The following table shows the angles which the most prominent points of the compass, the four primary and the four secondary, make with the meridian.

North		0°	0′	South	-
N by E	N by W	11	15	S by E	S by W
N N E	N N W	22	30	S S E	S S W
N E by N	N W by N	33	45	S E by S	S W by S
N E	N W	45	0	S E	S W
N E by E	N W by W	56	15	S E by E	S W by W
E N E	W N W	67	30	E S E	W S W
E by N	W by N	78	45	E by S	W by S
East	West	90	0	East	West

91. iii. Compass-box, As a general principle, it should be observed that, in common portable compass-boxes, intended for land-service, the needle moves freely on a pivot *over* the card, which is fixed firmly and evenly on the bottom of the box. The suspension of the needle in this case is a much more simple affair; and the box may be of any shape or construction, which may suit the convenience of the person using it. But the magnetic needle already described, and in use for a ship's compass, is placed *under* the card, along the north and south line; and when sus-

pended, the card will of course obey all the motions of the needle; by which means the points of the horizon are determined. Several other methods have been resorted to for the poising of the needles in the steering and azimuth compasses;—which have been more or less improvements, as they have produced a delicate suspension with easy and equable movement. The compass-box and the gimbals will be described further on: but the following representation, fig. 16, will give a sufficiently clear idea of the whole. The square box, in which the compass-basin &c. is included, is represented as wanting one of its upright sides, in order to show the interior arrangements.

Fig. 16.



92. When the compass is used to point out the direction in which a ship sails at sea, it is so placed in the ship, that the middle section of the square wooden box, which is parallel with the sides of the box, may be parallel with the middle section of the ship along its keel. When thus fixed, that part of the card, which coincides with a black perpendicular line marked within the compass-basin, otherwise white internally, and which black line is called the *Lubber's point*, will show the direction of the ship's head, or the part of the horizon to which it tends. In fact, it is the care of the steersman to keep that point of the compass towards which he is sailing, coincident with this line.

93. This—the mariner's or steering-compass,—is also sometimes called the *binnacle-compass;* because it is contained on board in a large wooden case, furnished with lights at night, and an hour-glass, and placed in front of the helmsman at the wheel. This case has the name of *binnacle;* and that the compass-needle may not be affected, no iron enters into the construction of the case.

94. The basin of this compass, being strong and heavy, and supported by gimbals, is very often inclosed in a box, only when not in use. When in use on board, the basin itself, together with its gimbals, is fitted into the binnacle.

95. A compass of similar nature, but inverted, is often fixed up overhead in the cabins of captains of vessels, that they may themselves superintend the course of the ship. This compass is called the *hanging* or *cabin-compass.* The bowl is hung up with the glass downwards, across which goes a brass bar with a point upward, on which the card moves. The brass cap carrying the agate is screwed into the needle the contrary way to the other compasses; the upper part of the agate being on the back part of the card instead of the front, as in the ordinary make.

96. Before we proceed with our description of the compass and the various uses to which it is applied, we must call the reader's attention to a point of first-rate importance, which long detracted from the utility of this instrument, and which has so often been the cause of shipwreck as to occasion great sacrifice of life and property. We refer to the local attraction which results from the masses of iron on board ship; whereby the needle is drawn, more or less, from the magnetic meridian, according to the situation of the disturbing causes with respect to the needle. This effect is called *the aberration of the needle;* and must be of large amount in ships of war, where the guns, shots, water-tanks, and frame-work of the vessel, are all made of iron.

97. It is remarkable that this, so evident cause of aberration, which must have existed ever since the magnetic needle was employed as a guide to the navigator, was in no wise suspected until almost within our own day. Mr. Downie, master of his Majesty's ship Glory, in the year 1794, was the first to demonstrate the cause of this evil; and to Professor Barlow is due the honour of furnishing the means for obviating its consequences, who thus added another splendid boon to the many, by which science benefits the human race.

98. We will first show how the aberration of the needle is ascertained on board ship; and in the second place state, as

briefly as we can, the nature of Professor Barlow's permanent correction of it.

If it be desired to know the true variation, or the aberration, of the needle when the ship's head is in a certain direction, the variation of the needle is to be observed when the ship's head is moved round alternately to the east and west points;—then half the sum of these variations will be the *true variation:* and half the difference will be the greatest *aberration of the needle*, from local attraction. Thus the effect of local attraction is traced; as for example—suppose, when the ship's head was brought east, (the observation being made in north latitude), the variation is observed to be 21° 40′ W.; but, when the ship's head was west, the observed variation was 28° 20′ W.:—We find

Variation Ship's head E.	21°	40′ W.		21°	40′ W.
Do. ———————— W.	28	20 W.		28	20 W.
	2) 50	0		2) 6	40
True variation	25	0	Greatest aberration	3	20

99. The reader will form an idea of the amount of error arising from aberration by consulting the following table, which Professor Barlow has given from the actual observations of the officers whose names are appended to each.

Ship.	*Place.*	*Observers.*	*Aberration.*
Conway . .	Portsmouth .	Capt. Hill .	4° 32′
Leven .	Northfleet .	—— Owen .	6 7
Barracouta .	Do. .	—— Cuttfield	14 30
Hecla . .	Do. .	—— Parry .	7 27
Fury . .	Do. .	—— Hoppner	6 22
Griper .	Nore . .	—— Clavering	13 36
Adventurer .	Plymouth .	—— King .	7 48
Gloucester .	Channel .	—— Stuart .	9 30

100. These examples will be sufficiently intelligible for the general reader, and we need not extend them. In practice, however, these observations must be made with an azimuth-compass (to be hereafter described); and this must be compared with the steering-compass, in order to be sure that the directions of the respective needles coincide. The azimuth-compass is used for the sake of greater accuracy. Moreover, it should be observed, before we go on further, that when the vessel is lying on the meridian, or north and south, this irregularity scarcely exists; because the mass of metal in the ship lies ahead northward or southward of the needle, and the local attraction is therefore in the line of the needle: whereas, when

the ship swings round to the east or west, the mass of metal has a tendency to carry the needle round with it. Thus, for instance, a ship's head being north, the variation is observed to be 24° 30′ W. The ship being directed eastward, the needle approaches towards the east; so that its apparent variation is reduced to 21° 50′ W. The ship's head being then turned westward, the needle is dragged round with it as much to the west of the magnetic meridian, or true variation-line, as it was in the former case to the east of it; and thus the real variation is increased to 27° 10′ W.

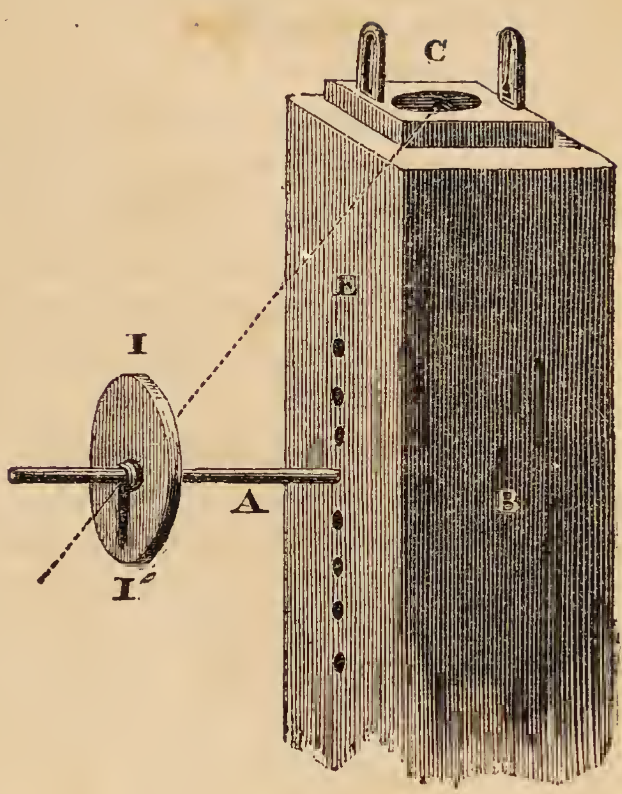
101. Professor Barlow began his experiments, by endeavonring to ascertain the action which masses of iron, of regular geometrical forms, exerted upon the needle; and he arrived at the following curious and important facts among many others,—that there exists round every globe or mass of iron, a great circle inclined to the horizon at an angle equal to the complement of the angle formed by the dip of the needle with the horizon; and also, that the plane of this circle is a plane of no attraction upon a needle whose centre is in that plane; and further—that the magnetic power resides entirely on the surface of an iron body, and is therefore independent of it as a mere mass.

102. From these important conclusions Mr. Barlow was enabled to construct an ingenious method of correcting the aberration of the compass, arising from the attraction of all the iron on board ships. As a hollow shell of four or five pounds weight acts as powerfully at the same distance, as a solid iron ball of 200 or 300 pounds, Mr. Barlow conceived that a disk of five or six pounds weight might be made to represent, and to counteract, the whole of the attraction of the iron on board; and consequently, that the needle might thus be left at liberty to yield to the action of the terrestrial magnetic force, in the same manner as if no disturbing cause existed in the ship; and though this idea was not fully carried out, (as we shall see,) yet this is the principle of the correction, which we are about to describe.

103. Mr. Barlow's Correcting Plate, or Magnetic Compensator, is shown in figures 17 and 18: where, in both cases, A, is a rod of brass or copper 1½ inch in diameter, and I I, two thin circular plates of iron 12 or 13 inches in breadth. A square foot of the metal of each plate weighs about 36 ounces avoirdupois. These plates are not in contact; but are separated by a circular piece of board or card, and pressed together by means of a brass nut at their centre on the end of the rod.

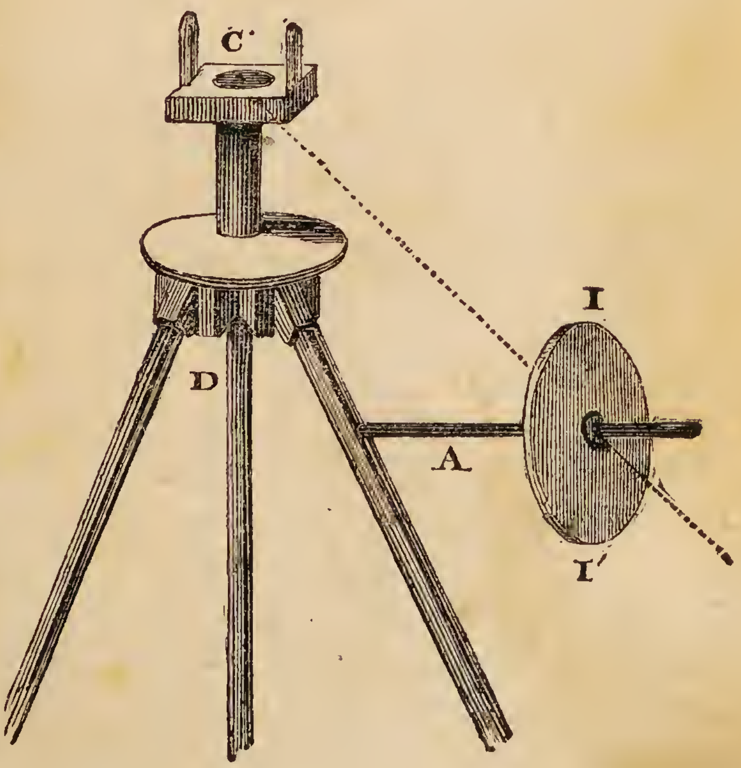
Other small screws are used near the rim of the plates, in order to make the union more even and complete. It appears that two plates are used, in order that any defect or irregularity in one may be corrected by the other; that the effects of a fall, or of a tendency to warp, may be thereby obviated; that a large extent of surface may be gained in a smaller space; and lastly, it is found that the plates are more powerful when separated than when in contact. Notwithstanding, a single plate would answer the end proposed; in which case, the weight of the iron must be double to the square foot.

Fig. 17.



104. In fig. 17, B is a box, moveable on an axis, in order that it may be turned round in any direction, as the head of the ship is turned round at sea. This box is used on land, and must have no iron connected with it. On the side, E, are various holes, for the reception and adjustment of the rod, A. An azimuth-compass, C, is fixed on the top. The apparatus, D, (fig. 18,) is used on board ship, to support the same azimuth - compass, C′; which sort of compass is chiefly employed in these observations, not only as being more portable, but as enabling

Fig. 18.



the observers to measure arcs of the horizon. Care must, however, be taken that this and the binnacle-compass agree in their indications.

105. We now proceed to show how Mr. Barlow's plate is generally used when it is wished to ascertain the true *variation* of the needle, and its *aberration* from the magnetic pole.

When a ship, being about to proceed on a voyage, has received all its metal on board, the variation of the compass, C′, is carefully noted as the ship's head is swung round to the principal (say the four cardinal and four secondary) points of the horizon. The box, B, with this compass on the top, is then taken on shore, and set down where it will be free from all metallic attraction. The object of the observer on shore is, by the adjustment of the plate, I I′, on the side of the box, E, as this box is turned round to the principal points of the horizon, (those mentioned before,) to produce the same, or similar, irregularities in the needle of the compass, C, on the box, B, as were occasioned to the needle of this compass, when on board, by the masses of iron in the ship. A little practice will soon enable any one so to adjust the plate, as to attain the object in view with tolerable accuracy. This having been effected, the distance from the centre of the plate to the pivot on which the needle turns, is carefully noted; together with the angle which the plate makes with a vertical plane. Whenever the plate is used on board, it must be fixed to one of the legs of the three-footed stand, D, (which usually supports the azimuth-compass during an observation) at the same distance from the centre of the needle at C′, and at the same angle with the vertical, as when inserted in the side, E, of the box, B.

106. As, by the foregoing account, we find that the plate was made to produce as much error as all the iron on board, we must observe, that when the plate is used on board, the error of the needle is consequently doubled. It is of course understood that, whenever the azimuth-compass is used, it must be placed in the position where it was just before taking the box, B, on shore; as the needle is variously affected in different parts of the vessel.

107. Now the action of the metal on board consists in *increasing* or *diminishing* the true variation; so that allowance must be made accordingly. If the variation of the compass *without* the plate, be observed to be 28°, and *with* the plate applied, 33°, it is evident, as the plate doubles the error, that the true variation is 23°: but if, in this instance, the application

of the plate had reduced the variation to 23°, it is clear that the first observation of 28° was 5° short of the true variation, or 33°.

108. We see then that the error of the needle caused by local attraction is doubled, whichever way the error may lie. It was Mr. Barlow's first idea, as we stated, that the needle, lying between two equally balanced forces, would be as free to move, as if it were completely removed from the neighbourhood of iron; but to effect this, the compensating plate must have been always in use and constantly shifted at every turn of the vessel, a consideration which naturally caused this notion to be abandoned.

109. The increasing quantity of iron used in ships, and especially steamers, which are sometimes constructed wholly of iron, makes it to be apprehended, that the compass will ere long cease to be a desirable aid to the navigator.

110. The correcting plate requires re-adjustment in latitudes where the dip of the needle varies greatly from what it is observed to be at the port where the first adjustment is made. Since two forces act upon the needle, a diminution of one force will, in many cases, allow the other to operate with greater effect. Thus, the first force spoken of is the earth's magnetism; the second is that which is occasioned by the metal on board. As the ship approaches the magnetic equator, the first force diminishes in intensity, and the needle approaches to equilibrium (as far as that force is concerned): the second force therefore acts with greater energy, and requires correction accordingly. A new land-observation should be made in order to re-adjust the plate; or, if this be found impracticable, an observation may be made in a boat, at such a distance from the ship as will secure it from the metallic influence existing in the vessel.

111. In process of time, it came to be noticed, that the rate of going of the chronometers on board ship, was more or less affected by the quantity of metal on board, or rather by partial masses near the chronometers; which masses, made temporarily magnetic, and acting, (as we said before,) as to their extent of surface, and not as to their solid contents,—produced such variations, either for *slower* or *faster* movement, as to disturb considerably the decision of the longitude by these time-keepers. The evil here spoken of had been noticed a great while ago, but had been imputed to the motion of the vessel on the seas; until Mr. George Fisher, who accompanied Captain Buchan in his voyage to the North Seas, in the year

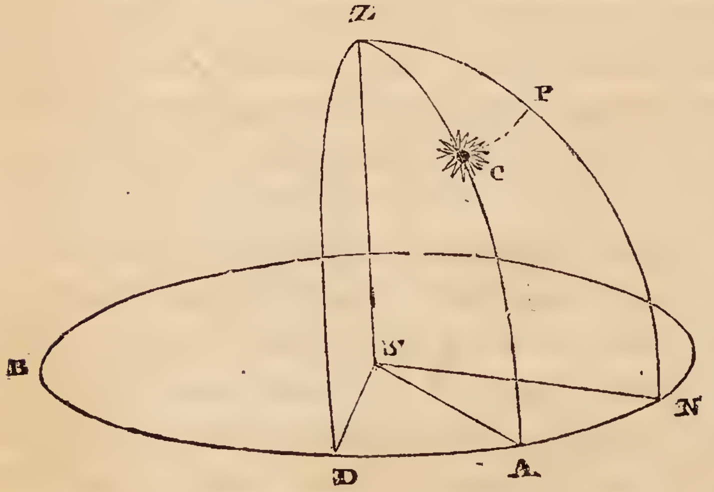
1818, pointed out the true cause of the evil, from observing that the chronometers had a different rate of going when on shore, to what they had when the vessels were quite still by being frozen in. The subject received much of Professor Barlow's attention; and the remedy suggested by him to meet the evil, is similar to, and dependant on, the same principles, as the experiment so sucessfully applied in the former case.

112. We will now turn our attention to describe, and to explain the use of, the Azimuth-Compass.

The term *azimuth* is a corruption of an Arabic compound word *as-samt*, *as* being the definite article *al*, and *samt*, a *way*, *path*, or *road*; also a part, tract, country, or quarter.

113. An azimuth is the angular distance of the horizontal point which is directly under a heavenly body, from the north point of the horizon. Thus in fig. 19, if S be the observer, Z his zenith or point exactly over head, Z N, his meridian, N A B, the horizon, then Z A will be the vertical or azimuth circle passing through a heavenly body, C, and cutting the meridian at the zenith, Z, and also at the nadir or point underneath, exactly opposite to Z, in the celestial sphere:—Z D, will be the prime vertical or azimuth circle passing through the east and west points of the horizon: the arc of the horizon, N A, or C P, above, measured in degrees, is the azimuth of the heavenly body, C, and the arc, A D, is the amplitude of the same.

Fig. 19.



114. Fig. 15, represents the card of a compass-box, which, having the needle suspended in the centre and free to move over the card, may be considered as representing a land-compass, and as being adapted merely for terrestrial purposes; but fig. 16, may be taken to represent a mariner's compass, by which the ship is steered, and also the azimuth-compass; which differs from the former chiefly in being furnished with sights, A B, through which any object may be seen, in order that the angle which it makes with the magnetic meridian may be determined. The two sights are situated vertically on the rim surrounding the top of the compass-basin. The sight, A,

to which the eye of the observer is applied, consists of a piece of brass in which is cut a narrow vertical slit; the other sight, B, is directed towards the object, and is also furnished with a slit or oblong aperture containing a fine wire, or horse-hair, passing vertically down the opening. These sights must be exactly opposite to each other, in such wise that a plane, connecting the sight A, and the wire or horse-hair in the sight B, would pass through the centre of the card and needle. The sights are sometimes connected at their upper parts, by a bar of brass, which tends to fix them steadily during an observation; and are sometimes removed when the instrument is not in use. Two lines are also continued vertically on the inside of the brass basin; one from the slit in each of the two sights. The use of the vertical line under the sight B, for instance, is that, when the compass-card is stopped by means of a small lever connected with it, which is pressed by the finger, as explained in fig. 14, (87) the degree on the rim of the card coinciding with this line, shows the measure of the angle intercepted between the rising point of the celestial body, and the magnetic pole. The reckoning commences from the north point of the compass, and proceeds eastward: thence to the south and west, 360 degrees in all; which are easily convertible into points; $11^\circ\ 15'$ making one point.

115. This compass, like the steering-compass before-mentioned, is held in a square box, fig. 16. The compass-basin is supported underneath by a semicircle of brass, C D, passing below the basin, and screwed firmly to the bottom of the box; and it is suspended horizontally by means of two opposite pivots, one of which is seen at *a*, passing from its sides into a hoop of brass E F, which hoop, by means of pivots from two extreme points *b c*, is connected with, and rests from the extremities of, the semicircle C D. These suspending hoops are termed *gimbals;* and it is obvious, that by this arrangement, the compass tends to the horizontal position, however the ship may be tossed upon the ocean. It is allowed on all sides that the English were the first to suspend the compass in this manner. The card, under which is the needle, turning on a pivot, which rises from the bottom of the basin, apparently floats round, as the whole apparatus turns about by the motion of the vessel. The compass-basin is covered by a circular piece of glass, that the motion of the card may not be affected by the air.

116. The method of using this compass, may be inferred from the preceding account of it. When, for instance, in

looking through the sight A, the sun, or a star, is seen to be bisected by the vertical wire in the sight B, the card is stopped by the handle, (fig. 14), and its angular distance from the north or from the east, as shown by the card, is seen; the former angle being termed the magnetic azimuth,—the latter, the magnetic amplitude. From these are computed the true amplitude and azimuth of the heavenly body, by certain formulæ in Trigonometry, furnished in works devoted to Nautical Astronomy.

117. The use of finding the amplitude or azimuth of the sun, or of any celestial body, being to ascertain the variation of the compass, in that part of the world where a vessel may be, we shall give an example of each sort of observation, with its result.

July 12, 1835, in latitude 42° 12′ s., and longitude 14° 46′ w., at 4 hours 35 minutes P.M., apparent time, the sun set NW. ½ W. by compass: required the variation?

	hrs.	mins
Time on board ship, July 12 . . .	4	35
Longitude in time	+	59W.
Time at Greenwich . . .	5	34

Sun's declination	22°	4′N.
Correction for 5 hours, 34 minutes .	—	2
Sun's declination by Greenwich time .	22	2 N.

Latitude . .	42° 12′s. . . .	Secant . . .	0·130296
Sun's declination .	22° 2′N. . . .	Sine.	9·574200
			9·704496

9·704496 is the logarithmic sine of the true amplitude, W.	30°	25′	28″N.
Amplitude by compass, NW. ½ W. = W.	39	22	30 N.
Variation . .	8	57	2 W.

March 8, 1835, in latitude 12° 36′ s., and longitude 155° 30′ E., at 6 hours 36 minutes, P.M., apparent time, the sun's magnetic azimuth was observed to be S. 79° 15′ W.—at the same time the altitude of his lower limb was 9° 46′; the height of the observer's eye being 16 feet, and the error of the instrument + 3′ 30″: required the variation of the compass?

	hrs.	mins.
Time on board ship, March 8.	6	36
Longitude in time	10	22E.
Time at Greenwich astronomically, March 7.	20	14
Sun's declination, March 7.	5°	26′s.
Correction for 20 hours 14 minutes	—	20
Sun's declination by Greenwich time	5	6 s.
	90	0
Sun's polar distance	84	54

Observed altitude of Sun's lower limb	9°	46′			
Correction	+	6	8″		
Index error	+	3	30		
True altitude of Sun's centre	9	55	38	... Secant	... 0·006552
Latitude	12	36		... Secant	... 0·010587
Polar distance	84	54			
Sum	107	25	38		
Half-sum	53	42	49	... Co-sine	... 9·772191
Remainder	31	11	11	... Co-sine	... 9·932215
					2) 19·721545
	46°	31′	45″	... Sine	... 9·860772
			2		
True azimuth from the north.	N. 93	3	30 W.		

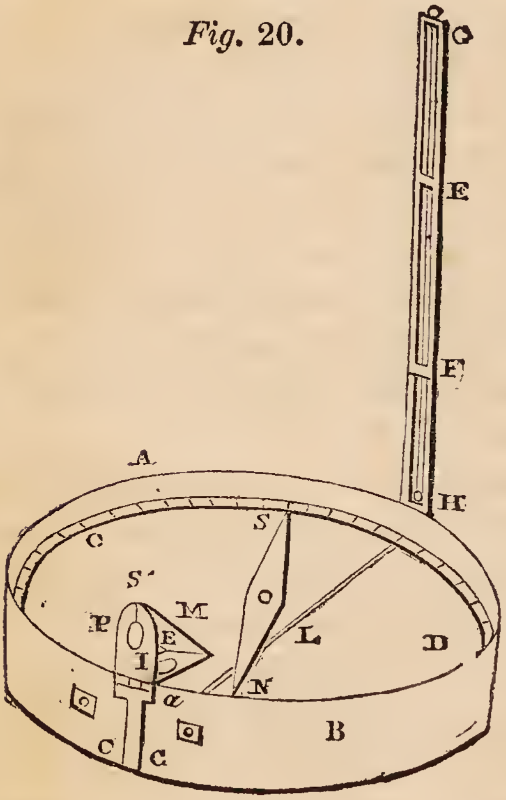
	180°	0′	0″	
	93	3	30	
	S. 86	56	30 W.	True azimuth from the south.
	S. 79	15	0 W.	Magnetic azimuth.
Variation	7	41	30 E.	

118. The foregoing account of the azimuth-compass illustrates the principles of its construction, and the purpose it serves towards correcting the ship's course at sea. This instrument is, however, frequently found to be deficient, where much accuracy is sought for, owing to the dull motion of the needle, which has to bear the weight of the card, and the imperfect mechanism for reading off the degrees. Complaints made by naval men on these heads, have incited many skilful mechanicians to remedy the defects; and several patents have been taken out for improved azimuth-compasses. We now proceed to give an account of a very improved instrument of this sort; as recommending

itself for its universal applicability, by land and sea, as well as by its cheaper price. The invention of it is due to the late Captain Kater.

119. This azimuth-compass is represented in fig. 20, where A B is a cylindrical brass box, one inch deep, with a glass cover. This box contains the compass-card C D, which is five inches in diameter, and the needle, N S, which is delicately poised on an agate cap, as before described in fig. 14. The needle is attached to a disk of talc, round the rim of which is laid a ring of card, graduated to half-degrees. A slanting piece of ivory is seen within the box just projecting over the margin of the graduated circumference of the card; and an index-line is marked on the ivory for reading off the divisions on the card. A brass sight-frame G H, is placed exactly at the opposite side of the box. It is a parallelogram in form, and five inches in length. A shorter frame E F, two inches long, slides up and down the frame G H: and contains the segment of a glass cylinder, whose radius is five inches. When the sun shines upon this cylindrical lens, its rays are collected into a linear focus; and the line of light being cast upon the index-line of the ivory projection may be seen at the same time with the degrees on the card. The frame G H can be bent down, when not in use, by means of a hinge at H; and when down, it presses upon a lever L, which raises the needle off from its point of suspension, and prevents it from moving about, and thus getting damaged.

Fig. 20.



120. The sight for the eye of the observer is one inch in height from the hinge *a*, to its upper part; but it may be raised a little higher by means of an upright piece, which slides between two grooves in the side of the box, as shown at *c c*. This upright plane has a narrow vertical slit S′, which terminates in a circular hole I, with a convex lens. There is also a horizontal plane below E, fixed beneath the circular hole I, in which plane there is also a convex lens, attached to which, at an angle of 45°, is a mirror, E, on the inner side of M, by means of which,

and the lenses, the observer, looking through the hole at I, sees the degrees on the card by reflection, reversed and magnified. The figures, expressing the number of degrees, should therefore be printed in reverse, so as to be read in their proper position, when seen through the lenses. The sight may be raised or lowered, in order to the adjustment of the focus.

121. The sun's azimuth may be taken by means of this instrument, in the following manner. With the frame G H raised, as in fig. 20, and directed towards that luminary, slide the cylindrical lens E F, up or down, till its linear focus falls upon the ivory index. The sight P, is then to be set up, that distinct vision may be obtained of the index-line on the ivory, through the two lenses. The line of light should be narrow, and well defined; if it be not so, slightly incline the frame G H towards the compass, till such is the case; taking care, however, that the sight is perpendicular to the horizon. This being done, the observer must incline the compass towards himself, so as to check the oscillations of the card by bringing it in contact with the index, and two pins fixed near it for the purpose. When the card is made steady, the compass must be inclined from the observer, as much as will just free the card from the index, and cause the line of light to be bisected by the index-line. The degrees and parts shown by the index-line may then be read off, while another observer takes the altitude of the sun. To this angle the correction on the card must be applied; whence will result the position of the sun with respect to the magnetic meridian. The degrees on the card of this compass are read from the north, eastward; and so on, round to 360°, as in the common azimuth-compass.

122. Captain Kater's compass is also employed in surveying. For this purpose the segment of the cylindrical glass is moved out of the way to the top of the frame G H; and then the horse-hair, or wire passing down G H, is distinctly seen. The hair or wire, in surveying, being viewed through the slit S′, must be made to bisect an object seen by direct vision, at the moment when its bearing by the card is viewed by reflection. This hair or wire is not used in observations of the sun; but must be applied when the amplitude or azimuth of a star is taken; and the segment of the glass cylinder is not used in terrestrial observations.

123. If the sight P be turned back upon its hinge *a*, outside the box, the line of light from the glass segment may be viewed, and the degrees read off, by the naked eye. This, how-

ever, requires some care, since the figures on the card are inverted, and error is thus likely to arise.

124. In the previous description, we have taken care not to stray far from Captain Kater's own account of the instrument; our object, however, being, in several points, to clear up the notice of it as furnished by other writers.

125. By referring to the table of the variation at London, we observe that the needle, which for many years had been deflecting westward of the north, is gradually returning towards the true meridian. It was further related, that the needle was daily subject to a systematic change of position; and also, that this daily change varied with the time of the year,—whence was deduced a monthly variation. This curious phenomenon has occasioned a series of elaborate observations from eminent magneticians, who have prepared the most accurate and delicate apparatus for scrutinizing the current value of this diurnal change. Such apparatus is termed the *Variation-Compass*. By means of this compass the diurnal and menstrual variations spoken of before, are nicely estimated. The most careful, complete, and delicate instrument of this sort, is that constructed at Paris.

126. The needle of the variation-compass is generally much longer than those belonging to the other compasses,—slender, regular, and highly magnetised; and is contained in an oblong box, which allows of a deviation of not more than about 25° from the central line; it never being necessary that the needle should describe any considerable arc. It must not rest upon a pivot, as in the former instances; as the friction resulting therefrom, though minute, is found to impede slight changes in terrestrial, or other extraneous magnetism. But when the needle is suspended at its centre by a very fine thread passing down a vertical tube, this defect is in a great measure remedied. The needle, which is carefully protected from agitation by the air, is seen through plates of glass at its poles, which move, each of them, over an arc carefully graduated. A vernier scale with a microscope, or common magnifying lens, thus furnishes very accurate indications of the daily and hourly changes in the position of the needle.

127. Though the diurnal and annual variation of the needle must be traced, for the most part, to the operation of the magnetism of the earth, yet the careful observer of diurnal variation will soon discover reason for taking into account those transitory causes, which will frequently produce similar effects.

While the aurora borealis prevails, the compass-needle is more or less disturbed. Dr. Dalton inferred this, at the latter part of the last century, from these four considerations:—1st, that when the aurora rose only 5°, 10°, or 15°, above the horizon, the needle was very little disturbed;—2nd, that when the aurora rose to the zenith, the disturbance was great;—3rd, that at Manchester, during these auroras, the needle would oscillate E., or W., as much as $\frac{1}{2}$°;—4th, that when the aurora ceased, the needle became quiet. Lightning and thunder are remarkable for affecting the polarity of the needle; and the compass has been frequently found to be disturbed by electricity settling upon the glass cover, which has escaped by wetting the glass. The state of the weather, changes in the atmosphere, which produce wind or snow, and even volcanic eruptions, have been observed to vary considerably the position of the needle. These considerations have been elucidated by many first-rate observers; as also by Professor Barlow, who, in his experiments on this head, neutralized the magnetism of the earth by placing one, two, or more magnets near the needle, and thus with a great degree of accuracy estimated the amount of the disturbing forces from the accidental causes enumerated above.

128. Many other beautifully delicate and accurate instruments have been contrived for observing the diurnal and other minute variations of magnetic elements; such as the dip, and the intensity. The most important we have now described; and we refer the reader, who is interested in the subject, and desires more complete details, to more elaborate treatises, which will be consulted with benefit to the student, who may wish, not only to read, but to experimentalize for himself.

129. In conclusion we may remark, that many of the variations in magnetic elements seem to be closely connected with the motion of the sun, with respect to the magnetic meridian. That branch of science called *Thermo-Electricity* reveals to us that electric currents can be produced in bodies by varying the temperature of their different parts. "This simple exciting principle transferred to the vast apparatus of nature, displays the most magnificent theory of terrestrial magnetism that the mind can possibly conceive. The sun is now the exciting agent, whose uniform tide of heat, sweeping the tropical zone, becomes the grand cause of a westerly circumflowing electrical flood: and thus converting the terrestrial ball into a thermo-electric magnet."—*Sturgeon*.

VII.

THE TUNING-FORK.

There is in souls a sympathy with sounds,
And as the mind is pitched the ear is pleased
With melting airs or martial, brisk or grave;
Some chord in unison with what we hear
Is touched within us, and the heart replies.—COWPER.

1. WHEN music is introduced among the members of a social circle, and a tuning-fork is employed to give precision to each instrument, and accordance among the whole, the thought seldom occurs to the musicians at such a time, that a wide range of scientific principles is involved in the action of that little regulator. The conclusion is tacitly admitted, that, if the tuning-fork by which a guitar, a violin, or a flute is tuned, yields the note A, for example, on one evening, it will yield the same note on any subsequent evening:—hence arises the dependance which we feel disposed to place upon it as a regulator of musical pitch. But all solicitude concerning the tuning-fork generally ends here:—why it emits a sound when struck, or why it should always yield the same sound, are questions which very rarely engage the attention of the musician.

2. But the principles, by which the sounds of a harp or piano-forte are emitted, are the same as those which regulate the emission of sound by the tuning-fork. Nay, more, the very principles, which make the string of a harp or piano-forte yield different notes at different times, are the same as those which make the pitch of a tuning-fork always the same. The *principle* is the same, but the *material* is different; and on that difference of material depends all the variation which a musical string experiences in pitch, and likewise all the correctness in pitch which distinguishes the tone produced from a tuning-fork.

3. As one of the objects of this volume is to show that much philosophy may be acquired by the study of common things, we hope to entice our readers to search out for themselves among the familiar implements by which they may be surrounded, materials for experiment, for the exercise of their

perceptive and reflective faculties. We propose, therefore, to make the *tuning-fork* the object of our present inquiry, and hope to be able to show, that a comprehensive knowledge of this little instrument will lead us into a wide and delightful field of research, easy of comprehension, and capable of affording a large amount of knowledge respecting the principles which regulate the action of musical instruments generally.

4. In order to accomplish our object, we will endeavour to furnish answers to the following questions:—

i. What is the cause of sound?

ii. Why do sounds differ in character from each other?

iii. Why do sounds differ in pitch?

iv. Why is a piece of metal, such as a tuning-fork, preferred, as a standard of pitch, to a stretched membrane, or string of cat-gut, &c.?

Section I.—1. What is the Cause of Sound?

5. No substance in nature, however compact its structure may be, or however dense and solid it may appear to the sight, is absolutely solid or incompressible. Let us instance two solids, which are respectively nearly at the extremes of the scale as to density, viz., Vesuvian pumice-stone and gold. The former we can see, with the naked eye, is extremely porous; little channels traverse its substance in every direction, so as to give to it all the porosity, but none of the symmetry, of the honey-comb. But when we regard gold, it is difficult for us to entertain the idea that it is porous: we balance it in the hand, and declare it to be very heavy: we cut it with a sharp instrument, and find a smooth surface presented to us, quite free from visible pores: we place it in water, and find that it absorbs none of that liquid: we apply a convex lens to it, and fail to distinguish porosity:—all this seems to lead to a clear conclusion, that the particles of which it is composed are in absolute contact, or in other words, that it is perfectly solid.

6. But science teaches us that such a conclusion must be added to the number of instances in which our visual powers are not to be admitted as witnesses respecting the properties of natural bodies, without the concurring evidence of superior testimony. In science "seeing" is not always "believing." That which is seen often requires to be submitted to the judgment, and to be examined by the light of strong analogy. We find from numerous processes in the arts, that gold, as well as all other substances, may be compressed into a smaller space

than that usually occupied. This being the case, we have to inquire how such compression can be effected? There are two conditions under which this operation could occur;—either, first, that the original atoms of matter which composed the gold are compressible; or, second, that, not being themselves compressible, yet being not quite close together, the atoms cannot themselves be reduced in size, but coming closer together, can be made to occupy, as a whole, a smaller space, by which means the substance is said to be *compressed.* A little consideration, however, will teach us, that no stability could exist in material objects, if the ultimate atoms of bodies admitted of compression. The splendid theory of chemical combination, which is now received among chemical philosophers, rests fundamentally on the assumption, that the ultimate atoms of any given body, although inconceivably small, are always of the same definite dimensions, however unable we may be to determine what those dimensions are. We have therefore every reason to conclude, that the compressibility of a solid mass is due to the existence of *pores*, or spaces between the particles of the body, which spaces are probably filled with some highly attenuated ether, which is supposed to be the matter or principle of *heat*, which tends to remove the atoms farther asunder.

7. We have here referred to solids. With respect to liquids, such as water, we have shown in our article on the Hydrometer, (11.) that all liquids are, to a certain extent, compressible. With respect to the third class of bodies, *i. e.*, aëriform fluids, our daily experience shows us that they are susceptible of compression into smaller spaces than they usually occupy. We have already in other articles given examples.

8. Having thus referred to the property of matter by which it admits of being reduced in bulk by pressure, we have now to consider the subsequent action,—that is, the return of a body to its original condition, after the disturbing force is removed. We shall find that a most extensive range of phenomena depends on the question, whether or not the compressed body regains its former bulk after the compressing force is removed: indeed, the very production of sound, in whatever way it may be considered, rests upon this point.

9. It is found that liquids and gases regain precisely the same bulk after pressure is removed, as they possessed before it was applied; but with regard to solids the law is not universal in its application. Let us instance the blade of a knife and a slip of lead of the same dimensions. We shall find that the knife on being bent will regain its former position, when the

bending force is removed, but the lead will acquire a permanent change in form. This may be illustrated thus:—Suppose A B, fig. 1, to be a section of the metallic slip, and the small dots to represent the particles of matter which compose it; the particles on the surface C, being as far apart as those on the surface D. If we now bend the slip of metal into the form represented by fig. 2, a change has taken place in the distance of the particles from each other; and not only so, but those on the one surface are separated farther asunder, while those on the other surface are made to approximate closer to each other. This is occasioned by the circumstance that the surface C becomes in the process of bending a portion of a larger circle than the surface D; and as there is the same number of particles in both, the intervals between the particles of the former must be wider than between those of the latter. Now the lead will submit to this disarrangement of its particles without much difficulty; because the intensity of the force by which the particles mutually attract each other is not so strong, but that it permits some of the particles to move slightly in position, so as to fill up the partial vacancies which the bending produces in the convex surface. But, with the slip of steel, this is not the case: each particle is held in a given position with respect to those around it; the particles resist strongly the disturbance caused by the bending, and will not change their position with regard to each other:—the particles on the convex side resist the formation of vacancies between them, and will not permit the entrance of other particles to fill up those vacancies. The consequence is, that, when the bending force is removed, the particles, urged by a strong adjusting process, return to their former state of approximation; which they are enabled to do, because no other particles have insinuated themselves into the temporarily vacated spaces. But the slip of lead does not return to its original state, because, in the first place, the tendency to do so is but weakly manifested; and in the second place, because the partially vacated spaces have become, during the process of bending,

Fig. 1.

Fig. 2.

occupied by other particles, which thus impede the return of those originally settled there*.

10. Observing these qualities, and their consequences, we now come to apply the term *elasticity* to the tendency of a body which is under pressure, or which is submitted to a disturbing force, to return to its former state, when such pressure or force is removed; and we distinguish degrees of comparison in different bodies, according as they develope much or little of this property. Thus, a wrought-iron bar or nail may be bent by a certain force; but when such force is removed, the metal does not return to its former condition: it acquires a convex and a concave side, and shows no tendency to return to its original form. But, if we operate on a cast-iron bar or nail, we obtain a very different result: we find, in the first place, that we cannot carry the bending process to a great extent without breaking the bar or nail; but, if we confine the pressure within the limits of the elasticity of the bar, it will regain its former position when the pressure is removed.

11. This has given rise to two kinds of elasticity,—each of which has its degrees of quantity,—the one perfect or imperfect, and the other extensive or limited: or, more correctly speaking, elasticity is estimated in two ways, as regards *perfection* and as regards *extent*. Thus a slip of glass has a perfect, but not an extensive elasticity: it is perfect, because it regains its former position when the disturbing force is removed; but it is not extensive, because, if the bending exceed a certain range, the glass will break. A mass of well kneaded dough has an extensive but not a perfect elasticity: it is extensive, because we may compress it into various forms; but it is not perfect, because it seldom or never regains its former bulk and figure when the pressure is removed. The same remark applies to a piece of lead. The well tempered spring of a chronometer, and the hair spring of a watch, are instances of almost perfect and extensive elasticity; and afford, perhaps, the most striking instances of elasticity ever manifested by solids: their elasticity is nearly perfect, because, although turned into a number of coils, they will return to nearly their former condition, when the bending force is removed: while at the same time the circumstance of their being so coiled, without breaking, obtains for them the character of extensive elasticity.

12. But these examples must yield to the elasticity of

* The reader is requested to remark, that this theory is only an assumption made in order to simplify the illustration of the varying elasticities of different substances.

gaseous fluids; which for perfection and extent far exceed all instances which solids afford. As for the extent of the elasticity of the atmospheric air, no limit is at present known to it: the most powerful machinery that we apply to press upon it, only reduces it in bulk, and although analogy teaches us to conclude that there is a point of condensation at which air would become liquid, yet no experiments have revealed to us what that degree of condensation is. With respect to the other mode of considering elasticity, that is, as perfect or imperfect, we cannot be far in error in calling air perfectly elastic; for if two cubic feet of air were condensed within the space of one cubic foot, and then the pressure removed, we know of no deviation from the law, that the air will again enlarge to the full bulk of two cubic feet. We cannot include vapours in the list with air; for pressure and reduction of temperature, one or both, speedily convert them into the liquid form.

13. If we now direct our attention to liquids, we shall find that we must give them the character applied to solids, rather than to airs: that is, the elasticity of liquids is perfect, but not extensive. We have stated, in the article on the Hydrometer, (22,) that water has been compressed $\frac{1}{27}$th of its original bulk; which bulk it regained when the pressure was removed: thus arises the designation of perfect, but limited elasticity.

14. We are now in a condition to understand what ensues when a body is pressed or struck. We may conclude, without danger of falling into error, that the body is, for an instant, compressed into less than its former bulk. Although an enormous force was found necessary to compress water within a compass differing but slightly from what it previously occupied, yet the law of continuity requires us to believe that a force of only one pound would produce a portion of that compression;—a portion certainly quite inappreciable by any of our means of measurement; yet, minute as it is, not to be neglected in our attempts to analyze the phenomenon. We may therefore state, as an axiom, that, whenever a body is pressed or struck, it is condensed by that operation into a smaller bulk than that which it originally occupied; although the amount of the compression, and the length of its duration, may be too minute for us to determine.

15. We must now request the reader's attention to a statement, for the due comprehension of which the preceding details have been given: that is, that, whenever a body is, by any external force, compressed into less than its usual bulk, and instantly regains that bulk, an effect is produced, which, when estimated or appreciated by the ear, becomes a *sound;* and

that, whatever may be the extent and variety of sounds presented to our perceptions, they may all be traced to a source such as we have here stated. Nothing can be more delightful to a student, who is engaged in inquiring into the operations of the physical world, than to arrive at such beautiful and simple laws as this. He then feels the truth of what, at an earlier period of his study, he would be inclined to doubt, namely, that perfection and simplicity may exist at the same time, and in the same law.

16. Let us now see whether we cannot refer to one principle all the different sounds, which strike upon the ear, at almost every waking hour of our existence.

Nature inanimate employs sweet sounds,
But animated Nature sweeter still,
To soothe and satisfy the human ear;

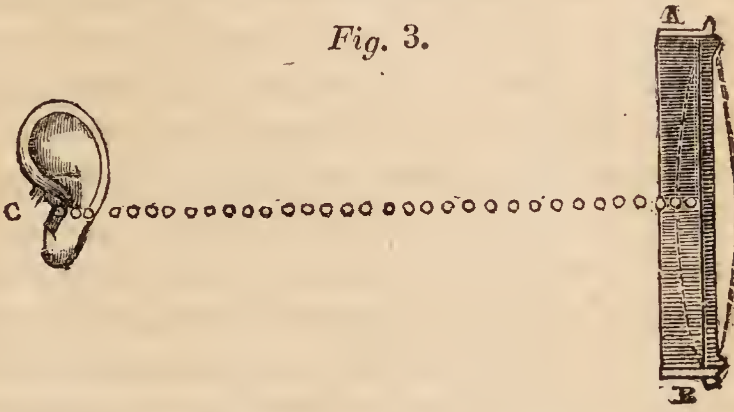
but all of them can be assigned to a cause, such as we have above alluded to. We must first, however, state that, as far as physiological inquiry has yet extended, the sense of hearing follows from the vibration of a membrane, stretched across the cavity or passage of the ear, which membrane is called the *membrana tympani*, or *membrane of the drum* of the ear. Within this membrane there is a complicated series of apparatus, consisting of a chain of little bones, curved vessels filled with water, cavities filled with air, and different structures of a membraneous, nervous, or cartilaginous nature: the object or purpose of all of which is not well known; but they are undoubtedly intended to conduce to the perfect appreciation of such external sounds, as are within the range of hearing of the human ear. We cannot enter further, in this place, upon the structure of the ear, but must be content with the statement that everything which sets the membrane of the tympanum, or drum of the ear, into a state of vibration, produces the sensation of sound.

17. The reader is aware that, under almost all circumstances, the external ear is in contact with the air, and as there is no obstruction or closing of the passage from thence to the membrane of the tympanum, we must conclude that the latter is likewise in contact with the air, and exposed freely to its action.

18. According to our definition, therefore, the air which is in contact with the membrane of the tympanum of the ear, must be in such a state as to communicate vibrations to it, whenever we experience the sensation of sound; and, as we also stated, that whenever a body is condensed and regains its first position, the phenomena are such as to produce sound, we may conclude

that the air itself is in a state of vibration, whenever we experience that sensation. How then does the air become condensed, and thus incited to the exercise of its native elasticity? Suppose A B, fig. 3, to be a section of the parchment head of a tambourine, and C an ear placed opposite to it, and that between the two is a row of particles of air, which we may represent by the small dots. When the tambourine is struck, as by the performer's hand, we still suppose the two ends of the section, (or the whole circumference in the instrument itself,) to remain stationary, because they are fixed to the frame; but the central part yields to the blow, and departing from the rectilinear position, assumes a curved form, concave on the side on which the blow was struck, and convex on the other side. But before it could assume that curved position, the particles of air nearest to it must be displaced; and, being displaced, whither are they to go? There is no vacancy on one side of them more than on another, and they cannot, therefore, assume a new position without, in their turn, displacing other particles. The same circumstance influences the second row of particles, and compels them to communicate the disturbance to the particles next beyond them. And thus the disturbance is communicated from one to another, until it reaches the ear at C. The reader may, if he please, conceive the particles of air to represent a row of little messengers, who give information to the ear, of the disturbance which the tambourine has undergone.

Fig. 3.



> The aërial flow of sound was known to him,
> From whence it first in wavy circles breaks,
> Till the touched organ takes the message in.

19. But while this is going forward, the parchment does not remain in the same curved position. It has an elasticity moderately extensive and moderately perfect; and as the particles of which it is composed, are forced further apart than their usual distance by that curvature, they strive to regain their former position, as soon as the hand is removed. When the membrane begins to recede, therefore, it leaves room for the particles of air to return to their former position; those nearest

to the membrane being of course the first to return. The whole of them in regular order come back to their wonted position; and the tympanum of the ear is relieved from a pressure to which it was subjected by the first impulse given to the particles of air.

20. Now this progression and regression is called a vibration, whether of the tambourine, of the particles of air, or of the membrane of the tympanum of the ear; and from such a vibration proceeds the sensation of sound. But it is very doubtful whether a single vibration, such as this, would produce sound, were it not closely followed up by others of the same kind. Although it has occupied some considerable time to put this description into words, yet the whole operation which we have described may not, perhaps, have occupied the hundredth part of a second,—a portion of time which we can scarcely conceive. If a tambourine-player were to strike his instrument as rapidly as he could, it is very probable, nay, almost certain, that it would make fifty or a hundred vibrations between two applications of his hand. The cause of this reiteration we must now show.

21. If a man engage to run a thousand yards in a certain number of minutes, he can never stop just at the end of his task, but will have to run a considerable number of yards in addition before he can bring himself to a stand. If a school-boy engage to jump over three or four benches placed side by side, he stipulates for "a run" previously to the jump. If a cricket-ball be thrown at a wicket, and fail to strike it, the ball will not stop when it reaches the wicket, but rolls along the ground to some distance beyond. Now the same mode of explanation will apply to the pedestrian, the school-boy, the cricket-ball, and the tambourine. They are all influenced by the momentum which is acquired by a moving body, and which prevents that body from coming to a stand at the moment that the moving force is withdrawn. The manner in which this acquired momentum is manifested in the three former instances which we adduce is sufficiently apparent to all; but it may not be so apparent that the same law applies to the membrane of the tambourine. Yet such is the case. When the membrane has attained its greatest displacement towards the left, it begins to return to its original position; but, in so doing, it acquires a velocity, or momentum, which will not allow it to stop at that point. It passes the position which it originally occupied, and travels onwards to the right of that position, and attains a convexity on that side very nearly equal to that which it had before

attained, on the left side; these two curved positions are delineated in the figure by the dotted lines. But when the second disturbance is produced, the same tendency to return is manifested: the membrane is nearly as much strained out of its natural position, by this second disturbance, as it had been by the first, and is urged to return with equal velocity. A second time does an acquired velocity carry it beyond the position of repose, and a second time must a retrograde movement occur, in order to attain this position.

22. Thus originates, and thus continues a series of vibrations, or oscillations, backward and forward, across the position of repose, or the position originally occupied by the membrane. But these vibrations are not of equal extent in consecutive portions of the series. No solid is absolutely perfect in its elasticity, nor is there a free medium in which the body can vibrate, because the air, however attenuated it may appear to us, is a material medium which resists the passage of any other body through it. From these two causes, the extent of the vibration (*i. e.* the distance to which the membrane departs from its original position) is continually lessening, until at last it is reduced to nothing. Were not this the case, if we struck the key of a musical instrument, it would continue to yield its sound without intermission; and all harmony would be lost, owing to the notes of one bar mingling with those of the following bar.

23. Thus then we see how it is that the act of striking the membrane of a tambourine gives us the sensation of sound. The margin of the instrument is confined by being fixed to a wooden rim, which also vibrates, but to so small a degree, compared with the membrane, that we do not here take the vibrations of the rim into account, but consider, that the only part which is in a condition to yield to the blow, is the central part, and that this can only yield by stretching its particles or fibres further asunder, in defiance of the natural tendency of the substance. When, therefore, the percussive, or pressing force, is removed, the fibres tend to return to their former state of approximation; but the energy with which they do so, carries them beyond the point which they strive to attain, and makes them assume a position almost as unnatural as before, but in an opposite direction. Now, as we suppose a row of particles of air to exist between the tambourine and the ear, and that these share the disturbance originally experienced by the tambourine, it follows that they must likewise feel the effects of the subsequent displacements, and oscillate or vibrate to and fro, as frequently, and as extensively as the membrane. Again: as the

tympanum of the ear is in constant contact with some of the particles of air, it likewise shares with them the vibrating action which they experience; and, whatever sensorial effect is produced by one vibration of the tympanum, is repeated as often as the particles of air, with which the tympanum is in contact, continue to vibrate.

24. Thus, then, we arrive at this conclusion; that, whenever the air with which the ear is in communication, is in a vibratory state, the mind appreciates that perception, which we call *sound*. It is doubtful whether the impulse communicated by one single vibration would be sufficiently intense to produce the sensation of sound; but, by being repeated with great rapidity, an aggregate sensation is experienced, although the individual members of that aggregate may be too feeble to produce the sensation singly.

25. Thus much for the effect of the vibration of a tambourine. But we must now be prepared for an extension of the law to other bodies. If we strike a bell, either with a hammer on the outside, or by means of the clapper within, the circular form of the bell becomes momentarily changed into the form of an ellipse; because the point at which the bell is struck, if the blow be from without, becomes slightly pressed in towards the centre, and in so doing forces out the portions on either side of it; while, if the blow be struck from within, the point which is struck is driven outwards in a minute degree, and thus draws inwards the portion contiguous to it. When we say forces or draws *outwards* or *inwards*, it must be understood that the amount of this displacement is immeasureably small; but small as it is, all the subsequent phenomena are derived from it. The parts, which were forced to the exterior of their wonted position, are by that action brought into an unnatural state, from which they strive to escape, by returning to their former situation as portions of the circular form; while those parts, which had been drawn to the interior of their proper position, at the same time return to the circular form by an outward regression. Now the generation of acquired velocity or momentum, alluded to with reference to the tambourine, maintains likewise in the present instance. The portions of the bell, which had been made to form the small ends of the ellipse by the percussion, in striving to retain their original position, overpass it, and assume a position within the proper circular form of the periphery; while the portions which had formed the sides of the ellipse are, by the same causes, carried too far outwards, and thus become the small ends of an ellipse, at right

angles to the former. This series of changes continues, until the resistance of the air and other causes finally bring them to a close.

26. Now, as particles of air are supposed to surround the bell, as well as the tambourine, it follows that those particles share with the bell, the vibratory action which it experiences; and further, that if the ear is in contact with those same particles, the membrane of the tympanum will likewise be set into a similar state of vibration; which will continue as long as the particles of air vibrate, and these, in their turn, will respond to the vibrations of the bell, as long as these continue. Thus, the same routine of effects follows from the vibration of the bell, as from that of the tambourine; and all this teaches us to expect, that similar results will be obtained with other vibrating bodies.

27. Let us consider the phenomena presented by a pianoforte. We press the finger on one of the ivory keys of the instrument, and we hear a resulting sound. Now, if we look at the mechanism of the instrument, we see that the key is at one end of a long lever, the other end of which carries a small hammer, with which a blow is struck on a piece of wire, situated either vertically or horizontally, according to the shape of the instrument. We, therefore, know that the sound emanates from that string, and it will be instructive to inquire how that sound depends upon the striking of the wire.

28. If we fasten one end of a piece of string to a nail, or to any other projection, and hold the other end between the fingers of one hand, and stretching it tightly, pull or draw it aside as we should the string of a harp, with one of the fingers of the other hand, we shall hear a sound; and the harder the string is pulled, the more decided and musical does the sound become. We likewise feel that the fingers which hold the string experience a pulling force at the moment that the string is made to produce the sound. Now the same train of explanation, which was applied to the former instances, will likewise apply here, with the modification rendered necessary by the difference in the form and nature of the substance. The act of pulling one end, while the other is fixed, gives the string a rigidity and firmness in the rectilinear position. But, when the string is drawn out of this rectilinear position by the finger of one hand, the strain felt by the fingers of the other, tells us that the particles of the string are in a state of unusual tension, and that they are striving to regain their former position. This they do immediately on the removal of the disturbing force; but, as in the former instances, momentum is generated by the

retrograde movement, and the string is carried beyond its position of repose.

29. In the case of the pianoforte, the string is firmly fixed at both ends, by being wound round screws or pegs, and it is drawn to a considerable degree of tension. The hammer, attached to the remote end of the lever, strikes the string at some point between the two fixed extremities, and influences it just as the hand did the tambourine; that is, the string becomes driven out of its rectilinear position, and is thrown into the form of a curve, the return from which gives birth to the momentum, which will make it vibrate to and fro across the position of rest. If we listen to the sound, the pedal being kept down, we hear it gradually decreasing in intensity, until at last it wholly dies away. This results from the decreasing extent of the vibrations, by which their power of exciting sound is more and more limited as they proceed, until the string is finally brought to rest. But, if we remove the foot from the pedal, we shall find that the duration of the sound is much limited. The former state is brought about by the circumstance that pressing on the pedal has the effect of removing the hammer from the string, and thus allowing it to vibrate freely, until the resistance of the air, friction, &c., bring it to a state of rest. But when the foot is removed from the pedal, the hammer is allowed to rest upon the string, as soon as the latter is struck, and thus to damp the sound by checking the vibrations; an effect which is desirable, in order to aid in the production of harmony, by preventing the notes of one bar from mingling with those of another.

30. The foregoing remarks will apply likewise to the string of a harp or guitar. The string is fixed at the two extremities, and the central part is drawn from its proper position by the finger, in order that its momentum may generate a series of vibrations, and thus communicate to the ear the sensation of sound. With regard to the violin the effect is different only from the circumstance, that the disturbing force is an assemblage of horse-hairs, instead of the fingers; but the succession of vibrations is caused by the friction of those horse-hairs against, or across, the string, and thus the sonorous vibrations are induced.

31. All the instruments, which we have here spoken of, are solids: but a similar train of effects results from the vibration of a column of air. When we blow into the *embouchure*, or mouth-hole, of a flute, we disturb the equilibrium of the columns, or rows of particles, of air; and this disturbance extends from one row to the others. The current of air which

we send into the flute, in order to force for itself a passage, must disturb the air already existing in the cavity of the flute; and thus influencing the mass of air at the farther end of the instrument, it sets the tympanum of the ear, with which the air is in communication, into a state of vibration: hence arises the sound which we are in the habit of saying emanates from the flute. The clarionet, the flageolet, the trumpet, the horn, the bassoon, &c., are so many contrivances, by which a column of air may be set into a state of vibration by the performer, who sends a blast of air into the tube by means of the mouth;—the bulk and velocity of the blast of air having much influence on the perfection of the sound produced. In this light, also, may be viewed the production of sound by the voice: the lungs may be considered as the performer, who sends forth a blast of air; and the trachea, or windpipe, as the musical instrument, into which that blast is propelled. A complicated assemblage of cartilaginous and muscular apparatus modifies and perfects the sound emitted; but the fundamental portions of the apparatus are what we have stated, viz., the lungs to furnish a blast or current of air, and the trachea to perform the office of the tube or musical instrument.

32. In an organ-pipe, the bellows is the performer, who sends a current of air into the pipe; the keys of the instrument being merely the means of opening or closing valves, by which the admission of air into the tube is regulated. It is in this light that the organ-blower viewed the value of his own services, who insisted that the plural pronoun "we" should be applied to the object of applause, when a piece of music was well performed. It is undoubtedly true that the performer, who presses down the keys, requires and displays the greater share of talent, but yet all his talent would be nugatory, unless the organ-blower sent a blast of air into the pipes.

Fig. 4.

33. Now the reader must be prepared to expect, from all that has been said, that a tuning-fork produces its accustomed sound on principles analogous to those which we have been describing above. If we suppose A B, fig. 4, to be the two prongs of a tuning-fork, seen edgeways, we shall understand that, if one of them, as A, be struck against a table, in the usual manner, it will assume the position (*b*),—that is, it will be forced nearer to the other prong B. But its elasticity will not permit it to retain that position. In a minute fraction of a second of time, it will return to

its former position A; but in so doing, the effect, before detailed, will be produced, viz., the generation of a momentum, or velocity, which will carry it beyond its original position to the position (*a*), about as far from A as was the position (*b*): and thus is brought about a series of vibrations similar to those of which we have already spoken.

34. But, in the present instance, an augmentation of the effect is produced by having another prong B near the first; and the manner in which that augmentation is produced, is as follows:—When the prong A is first disturbed from its position, and driven towards B, the air between the two prongs must necessarily be disturbed likewise, and, in turn, must disturb the prong B, which is by that disturbance made to assume a position to the right of that which it would properly occupy. This communication of vibratory action is likewise assisted by the metal which joins the two prongs. The circumstances which caused the first prong to vibrate to and fro, will now influence the second; from which comes another consequence, viz., that they reciprocally assist and augment each other's vibration, and thus increase the sound-producing forces.

35. In order now to furnish a test of the truth of the statement, that, to experience the sensation of sound, the ear must be in communication with a vibrating body, we may state that, if a bell be rung in a hollow space totally deprived of air, no sound is detected by a person standing near the apparatus. It is a common experiment in scientific lectures, to suspend a bell under the receiver of an air-pump, to exhaust the air within the receiver, and to cause a hammer or clapper to strike the bell. Although the head of the experimenter may be within a few inches of the receiver, and he may see the hammer strike the bell, yet the faint sound which is heard appears to come from a small bell rung at a great distance from the ear. If the receiver containing the suspended bell be exhausted, and the vacuum filled up with pure and dry hydrogen gas, and the receiver be again exhausted to a pressure, as indicated by the mercurial guage, of half an inch, the vibrations of the bell will be absolutely inaudible. In this experiment it is curious to regard the clapper in rapid motion, distinctly striking the bell, and producing no sound even when the head is almost in contact with the receiver. This effect is calculated to call to mind the disheartening feelings which a deaf person must entertain on witnessing a process which he knows must produce sounds, but which sounds he is incapable of hearing. If now a little air be allowed to enter the receiver, the sound emitted by the bell

becomes slightly audible,—thus affording an analogy to the effect produced by bringing a distant bell nearer to the ear. As the quantity of air increases in the receiver, so does the audibility of the sound increase, until at last it attains the usual degree of intensity under ordinary circumstances.

36. Now if we inquire into the rationale of these occurrences, we shall find that the inaudibility of the sound proceeds from the circumstance that there is no medium in which vibration can be induced. The hammer or clapper strikes the bell, and changes its form from the circular to the elliptical; and thus, so far as the bell is concerned, the state of things is the same as in the atmosphere. But, as regards the surrounding medium, the circumstances are changed: there are no particles of air to receive and share with the bell the vibratory action which the hammer produces on the latter; and as there is no air to convey the vibrations, the glass receiver is not subject to the impulse, and therefore it cannot in its turn vibrate. We may consider that there are four media between the hammer and the ear, viz., the bell, the space surrounding it, the glass receiver, and the space between that and the ear. Now, unless there be real material substance to form the chain connecting one with the other, no sound is appreciated by the ear; when therefore we remove the second link of the chain, that is, the air between the bell and the receiver, we, in effect, break the chain, and isolate the bell: it continues vibrating, but those vibrations cannot reach the ear, because of the want of a vibrating communicator between the bell and the glass receiver. It is proper to remark that an absolute vacuum is never produced by the air-pump; but such a degree of rarefaction of the contained air may be produced as will have nearly the same effect as a perfect vacuum in stifling sounds, or rather in refusing to propagate them to surrounding bodies. With respect to hydrogen gas, this medium is so thin, that, even when a bell is rung in a receiver full of it, the sound is scarcely audible. Sound is transmitted through common air with the same degree of rapidity, however much it may be rarified; but in hydrogen gas it is more than three times swifter. "The bell, therefore," as Professor Leslie remarks, "strikes a medium which is at once thin and fugacious; fewer particles are struck, and these sooner escape from the action of the stroke."

37. Thus, then, we arrive at the conclusion, that, whenever we hear a sound, we may be certain that there is a body, solid, liquid, or aëriform, more or less near to us, which is in a vibratory state; that the vibrations produced are communicated

to the air immediately surrounding the ear; and that the particles of air, in contact with the membrane of the tympanum of the ear, communicate to it, in their turn, the vibratory action, which they have already received.

Thus we have endeavoured to furnish a full answer to the first question,—" What is the cause of sound?"

SECTION II. WHY DO SOUNDS DIFFER FROM EACH OTHER IN CHARACTER?

38. This question involves the consideration of those particular circumstances, which distinguish musical sounds from *noises*, and the musical sounds of one instrument from those of another; and the discussion of this question will lead us to some curious and instructive results.

39. There seems to be implanted in the mind a love of regularity, or the recurrence of similar objects or phenomena at equal intervals. Dancing derives much of its attraction from this source. A measure, or metre, is agreed upon,—whether it be $\frac{2}{4}$ time, or triple time, or any other that the composer may choose to adopt; and there is a feeling of pleasure experienced at seeing the feet of the dancers obey the measure of the tune. Perhaps, at the beginning of each bar, there is a motion of the body or of the feet more emphatic and decided than at the middle or end of the bar; and even a bad dancer gains greatly in the favour of his associates, if he carefully attend to the *rhythm** of the dance (so to speak), or to the *time* in which each series of movements occurs. While, on the other hand, a dancer, whose movements are really elegant, is considered rather a detriment than an advantage to the circle of dancers, if he do not time his movements well.

40. A part of our love of poetry is derived from a similar source. The greater portion of our admiration is, of course, directed to the ideas of which the words are but the symbols; but yet there is a pleasure quite independent of the mental beauty of a poem, and which consists in the recurrence, after equal intervals, of words having a similar sound. Children, before they have arrived at an age to appreciate poetical beauties, like to repeat short tales and stories in verse; and there is no doubt that they do so from a feeling of pleasure, arising from a succession of similar sensations of a two-fold character, viz., the

* This word is derived from the Greek, and implies the doing of any thing *according to certain regulated times or measures.*

number and order of the syllables in a line, and the rhythm belonging to them; which combined, we call *metre.*

41. It is to such a source as this that we are to look for the origin of musical pleasure; or in other words, if there be two series of sounds appreciated by the ear, that series which is the more regular in the recurrence of its component parts, is appreciated as the more musical of the two. Let us draw a nail or piece of iron across the teeth of a saw, and notice the results. Every time that the nail touches a tooth a sound is produced, from two sources: first, the little film or body of air between two teeth is condensed or forced against the tooth which is struck; and second, the metal which composes the tooth is thrown into a vibratory state. Now if we only struck one tooth, we should hear a sound, though not so audible as to excite much attention; but when we pass the nail rapidly along the edge of the saw, so as to strike a number of teeth in rapid succession, we hear a grating noise which is peculiarly disagreeable to the ear. If, however, we were able to pass the arm along with a truly equable motion, so that the interval between the striking of two teeth should be exactly equal, we should then produce a musical sound. We may illustrate this by reference to friction against the teeth of a fine file, in which there may be perhaps ten teeth of the file in the same length of space as one tooth of the saw. In this case, the motion of the nail, as moved by the arm, is much more equable as compared with the size of the teeth, than was the case when the teeth of the saw were struck. We shall find that it is easier to produce a musical note by rapid friction along the teeth of a file than along those of a saw.

42. Now to apply this to the sounds emitted by musical instruments, we must speak of a property of *isochronism,* or *equal-timedness* in the vibration of elastic bodies. If we attach a ball to a piece of string, and suspend it from a nail, and then put it into an oscillatory state by drawing it on one side and letting it fall again, we shall find that the ball performs all its oscillations in equal times, whether these oscillations be extensive or limited. In the case of extensive vibration, the greater velocity makes the ball move more quickly through any given space: while in the case of small vibrations, that limited extent is made up by the slowness of the motion; so that the ratio between the velocity and the extent of the vibration is very nearly equal under all circumstances, whereby the time, which the ball takes to perform a complete vibration, is equal, whether the excursions be great or small.

43. The same remark will apply to the vibration of an elastic body. In speaking of the tambourine, we said that the extent of its vibrations, or departure from the position of repose gradually decreased from the first impulse, communicated by the hand, till the entire cessation of vibration. But it is important to know that every vibration was performed in the same time: whether large or small, the vibrations at the beginning were as rapidly performed as those near the end of the operation. From this it follows, that the air, situated next to the membrane of the tambourine, likewise performed its vibrations in equal times; and lastly, we may apply the same remark to the tympanum of the ear. If we suppose that every time a particle, or a small stratum of particles, of air presses upon the ear, a sound is produced, it follows that those sounds, under the circumstances that we have just considered, would succeed each other isochronously, or there would be an equal interval between each two of them.

44. Now this it is which constitutes the difference between *musical* sounds and those sounds to which are generally given the appellation of *noises.* If a tambourine be struck, the resulting vibrations are isochronous, and communicate isochronous vibrations to the air, which, in its turn, excites a similar action on the tympanum of the ear. A tuning-fork consists of two prongs, which are connected at one end by the handle; and when the other end of one of the prongs is struck, it vibrates to and fro, the axis or hinge being the point of contact between the prong and the handle. These vibrations, like those of the tambourine, are isochronous, and thus produce a sound which the ear distinguishes as being of a musical character. A string, such as of a violin or harp, is fixed in a manner different both from the membrane of the tambourine and the prong of the fork; being fixed at two ends, and free to vibrate in the middle. But though thus different from the other two instruments, it resembles them in the law of their vibration, that is, the vibrations are isochronous.

45. The same remarks apply to all the varied kinds of musical instruments, however much they may differ from each other in construction, material, or mode of using. But when we come to consider other sources of sound, such as a coach rattling over the stones of a street,—a saw cutting through a piece of wood,—and numerous other instances which will occur to the reader,—we have no reason to believe that the percussion or vibration, which produces the sound, will be isochronous. With regard to a wheel passing over stones, the sound is occa-

sioned principally by the concussion of the wheel with each successive stone; and if the stones were precisely equal in size and distance, and the motion of the wheel perfectly uniform and very rapid, it is probable that a musical sound would result from the rapid and isochronous repetition of those concussions; but in practice, the stones are never sufficiently equal either in size or in distance, nor is the motion of the wheel sufficiently equable, to produce the effect of a musical sound. The same may be said of a saw: the grain of the wood does not present equal resistance at every part, and although the teeth may be of nearly equal size, yet the motion of the arm in the act of sawing is very unequal; so that, taking all the circumstances together, the percussive impulses are not isochronous.

46. But we will take an instance which admits of more ready comparison with musical instruments. Let us compare the sounds produced by the coppersmith and the plumber, in the course of their respective employments. The former, in the act of hammering the sheet-copper on which he is operating, produces sounds of considerable intensity, and not unmusical in themselves, but rendered so by many different sounds being heard at the same time. The plumber works on a material of very little elasticity: the lead, on receiving a blow, yields much more readily than the copper; and in thus yielding, shows the small elastic power which it possesses. If we fix a slip of lead into a vice, or any contrivance to grasp it firmly, and bend it slightly out of its straight position, it will return again, yielding a slight sound; but its return is not by strictly isochronous vibrations; its vibrations are unequal among themselves, and thus fail to produce a musical effect. If the slip of lead be bent somewhat more extensively from its original position, it will not return to that position, but will take up a new form in consequence of the disturbance.

47. Now, whenever these properties are manifested, the vibrations of the body are seldom isochronous; and hence the bodies fail to yield a sound such as we term musical. Thus arises the distinction between musical sounds and such as are not musical. There are indeed other minor details which influence the decision of the question; but to the principle of isochronism the effect must be essentially attributed.

48. This, then, being the cause of difference between musical and unmusical sounds, we must inquire what gives rise to the great variety in the character of the sounds as emitted by different instruments.

This we shall find to be the combined effect of the materials

of which the vibrating bodies are composed,—the manner in which they are fixed, and in which they are played upon. With regard to the first point, we find a great variety. The vibrating body in the piano-forte, the violin, the harp, and the guitar, is either animal membrane formed into the shape of a cord, or wire, or a combination of both. The drum and the tambourine are likewise formed of animal membranes; but instead of being formed into a chord, they are spread out into a large, smooth, thin, circular surface. Cymbals consist of two pieces of metal, whose surfaces are clashed together. The triangle is a rod of metal, bent into a three-cornered form, which being freely suspended, is struck by another piece of metal. The tuning-fork consists, as we have seen, of two prongs of metal, parallel with each other, and united at one end only. The organ, the voice, the flute, the trumpet, &c., are columns or tubes filled with air; the air being itself the vibrating body.

49. Now with regard to the second source of difference of sound,—that is, the mode of fixing the vibrating body,—we find that in the piano-forte, harp, violin, guitar, &c., the wires or strings are fixed at both ends, with a contrivance at one end by which the string can be brought to a considerable degree of tension. The vibrating body of the tambourine and drum is fixed all round their circumferences, where, by means of stretchers contrived for that purpose, it is brought to the requisite degree of tension, while the middle portion of the membrane is free to vibrate. With respect to vibrating columns of air, it is scarcely correct to say that they are fixed at any part; but there are various arrangements by which the extent of the vibrating column can be increased or diminished according to circumstances, such as the finger-holes in the flute, clarionet, &c., the mechanism in the interior of an organ-pipe, and in the interior of the trachea or windpipe, &c.

50. The third modification, or that which depends on the mode of playing the instrument, is as diversified as the other two. In the piano-forte, we strike the wire at a point between its two extremities, in a sharp and sudden manner, with a soft hammer,—the blow being given precisely at right angles to the length of the wire. In the harp, we pull the string out of its rectilinear position with the fingers,—sometimes at right angles to the plane passing through all the strings, at other times in an oblique direction,—and the string is then left to attain its original position. In the violin, the string is drawn out of its position by the bow; and there is no musical instrument by which greater diversity of effect is produced, through different

modes of performing, than the violin;—sometimes a vibratory motion, nearly rectilinear, is induced on the string,—while at other times it performs a series of complicated rotatory vibrations, in consequence of the peculiar way in which the bow is handled by the performer. The principal difference between a Paganini and a blind fiddler in the street, results from the mode of drawing the strings out of their wonted position. Doubtless, the perfection of the instrument, the exquisite ear and musical skill of the performer, and the facility in the motion of the fingers, all tend towards the success of the former musician; but the richness and beauty of tone mainly depend on the mode in which the bow is handled, or on the mode in which the strings are made to vibrate. In wind-instruments, the modes of excitation are very various: in the flute, we blow a thin contracted blast of air into a hole at the side of the tube; in the clarionet, we blow through a small orifice at the end, within which is a tongue or reed, which is set into a vibratory state by the current of air forced into the orifice, and by its vibrations, modifies the freedom of communication between the orifice and the column of air in the tube. In the trumpet, the mouth is drawn up into such a position as to propel a narrow, but very powerful current of air into the tube, and thus to produce an effect wholly different from that which would result from blowing into the trumpet in the same manner as into a clarionet or flute.

51. In whistling into a small key, or in blowing into one of the pipes of a common mouth-organ, another mode of exciting the contained column of air is adopted: the mouth is held obliquely over the top of the orifice, in such a manner, as to send a very thin film or current of air into the tube.

52. Our readers must have frequently noticed the manner in which a tambourine-player varies the sound of his instrument by altering the mode of applying his hand to it. In general, he strikes the tambourine with the back of his fingers, but at other times he slides the end of the finger or thumb along the surface, by which he produces a rapid succession of interrupted vibrations, very different in character from the continuous vibrations resulting from the direct percussion of the membrane.

53. The reader is of course familiar with the mode of sounding the tuning-fork, by striking one of the prongs against a hard substance, and then resting the handle upon a good sound-conducting substance. But this plan is very imperfect, compared with the mode generally practised in France. The vibration is produced by means of a cylinder of wood, which is

inserted near the point of juncture between the two prongs, and is then moved suddenly upwards, so as to clear the prongs in forcing them further apart. On being thus disturbed, they vibrate with equal force and velocity, and the sound is considerably augmented. In this mode of vibration, the two prongs of the fork are not made parallel, but widen near the point of juncture; somewhat in the form of a horse-shoe, so as to admit the wooden cylinder at the widened part. The bottom of the handle of the fork, or the end furthest from the prongs, is sometimes formed into a flat surface, so that, after the prongs are set vibrating, the fork may be left to itself, or the fork may be a fixture in a block of wood: all then that is necessary, is to pass the cylinder up between the two prongs, and they will continue to vibrate for a long time.

54. These are a few of the sources of the great differences observable in the character of the sounds yielded by different musical and other instruments. But there is another source altogether different from these, which results from the use of sounding-boards, attached to some part of the vibrating apparatus.

55. We will previously remark, however, that the French language contains a very convenient term for distinguishing different characters of tone,—this is, "*timbre.*" Thus, the sound of a flute is of a different timbre from that of the clarionet, &c.

56. If we consider the construction of a violin, we perceive four strings stretched tightly by attachments at each end, by which the strings are drawn to a great degree of tension. The strings are elevated at one point of their length, by being made to rest on the edge of a bridge, an inch or an inch and a half in height; thus allowing free scope for vibration between the bridge and the nut. But this is not all: we find a hollow box of wood placed beneath the strings, which box consists of a curiously curved face and back, separated by sides an inch or more in depth. Now when the strings of the violin are set into a vibratory state, they necessarily communicate a similar impulse to the surrounding air; but they also communicate a vibratory tendency to the box or body of the violin through the medium of the wooden bridge; by which means the upper surface is made to vibrate. These vibrations again are further communicated to the lower surface, or back of the instrument, by two modes: one of which is, a wooden peg or sounding-post placed perpendicularly between the two surfaces; and the other is the stratum of air existing between them. We have thus a

solid conductor, and a conductor of an aëriform nature, between the strings and the face of the violin; and another pair of conductors, the one solid and the other aëriform, between the face and the back: and through the agency of these conductors, the whole apparatus is made to vibrate.

57. Now the effect, which this augmentation of vibrating surface produces on the sound, will be easily conceived. When the string alone vibrates, the surrounding air is struck by a very narrow line or cord, and therefore receives but a weak impulse from those vibrations; when, however, a large surface, such as the body of a violin, is in a state of vibration, a large number of particles of air is set into motion at once, and thus the sound is greatly increased. That this is the effect produced by the bodies of the instruments may be confirmed by a comparison between the tones of a dancing-master's kit, of a violin, of a violoncello, and of a contra-basso or double-bass. In these four cases, the strings certainly differ in length and thickness, but that difference is quite inadequate to produce the very great difference as regards fulness of tone. In a theatre the kit would scarcely be heard, while the double-bass produces sounds which sometimes make the benches of the theatre tremble: the violin and the violoncello are intermediate between these two. If the reader have an opportunity of making experiments on the vibration of strings of every size in use for these instruments, and if he vary their tension by means of a convenient apparatus, he will find that the result of the increase of intensity in each string, from the smallest to the largest, is not comparable to that which would result if the strings were attached to their proper wooden cases.

58. The very great difference observable in the tones of different violins, when in the hands of the same player, results chiefly from the different nature or texture of the wood of which the body of the violin is made. A very old violin, and a new one made of the same shape, and of the same kind of wood, will yield very different tones,—those of the older instrument being far better than those of the new. It is this circumstance which gave so high a value to the old Cremonas and Amatis, and which rendered it very doubtful whether any modern violins could equal the old ones, until Savart applied his ingenuity to dispel this doubt, aided by a perfect knowledge of the scientific principles which regulated the action of the instrument, and which had not previously been investigated; so that the production of a good violin, even in the hands of a first rate maker, was a matter of chance; as, indeed, it always will be, until

musicians and instrument-makers will condescend to study, in detail, the scientific principles on which the practice of their art depends.

59. It will be instructive and interesting to the reader if we interrupt the order of our course to describe the violin as constructed by Savart.

The great object of this philosopher's researches, was to determine what were the essential elements of the violin, and what were merely ornamental or empirical details. On considering the principle of the instrument, he arrived at the opinion that the vaulted or curved form of the face and back is not a necessary part of the structure. In the experimental violin which he constructed, he employed flat surfaces of very thin wood. The face and back were each formed of two pieces, similar and equal to each other,—$2\frac{3}{4}$ lines thick at one edge, and gradually tapering towards the other edge, which was about 1 line thick; the thick edges of the two were then joined together. The next peculiarity which we may mention is, that the sides of the instrument were straight instead of being fancifully curved, as in ordinary violins. The reason for this change was, that the sides might enter into undisturbed vibration from corner to corner of the instrument, and thus aid the sound, which is prevented in the common construction. The form of the instrument was that of a trapezium, or four-sided figure, of which the end near the handle was shorter than the remote end. There is, in common violins, a bar, called the bar of harmony, passing along the under surface of the face of the instrument, for the purpose of strengthening it. This bar is placed a little on one side of the middle line or axis of the instrument, and the sounding-post, or *soul*, is placed at a short distance on the other side. Now this is a defective arrangement, as the bar stiffens, and retards the vibration of one side of the axis more than of the other. Savart, therefore, placed his bar of harmony along the central axis, and thus equalized the vibratory power on the two sides of it.

The sounding-post has usually been considered as a kind of support for the upper surface, but Savart found that its only effect was to communicate the vibrations from the face to the back of the instrument, and the point at which he fixed the post in his violin was such as to convey the sonorous vibrations more perfectly and energetically from the face to the back of the instrument. An improvement was next made in the perforations on the face of the instrument. Savart covered the two holes on the face of a violin with paper, and found that the

sound was very materially injured thereby: this he attributed to the stoppage of communication between the air within the body of the instrument and the external air. Having thus determined what was the real office performed by these holes, he next directed his attention to the form in which they are generally made. This form represents an Italian *S;* but Savart considered that the margin of such an aperture must necessarily be variously affected in its vibration, according as it coincided with, or was inclined to, the direction of the fibres of the wood. He accordingly made those openings in the form of a parallelogram, that is, the edges were straight and parallel. By this arrangement the fibres, and the margins of the holes, were in the same direction, and the vibrations of the wood at those parts were rendered more symmetrical, while at the same time fewer fibres were cut.

There can be no doubt that many parts of ordinary violins tend to damp rather than to improve the tones. Accordingly, Savart took every precaution to ensure co-operation in every part of his violin, as much as possible. Before the instrument was put together, he brought the tablets, which were to form the face and back, into precisely the same vibratory state; so that each one should yield the same sound, and the same nodal distribution of sound on its surface, as the other. He conjectures that the old makers were cognizant of the importance of this adjustment.

60. Here then we see in how many ways Savart's violin differed from those ordinarily constructed. 1st. The tablets were flat. 2nd. They were thicker, and therefore stronger than the ordinary curved tablets, their flat form rendering them capable of vibrating more readily. 3rd. The bar of harmony was so placed as not to stiffen one half of the face more than the other. 4th. The soul, or sounding-post, was placed so as to convey the vibrations from the upper to the lower tablet more energetically. 5th. The sides of the instrument were made straight, so as to add, by their facility of vibration, to the sonorous effect. 6th. The apertures in the upper tablet were straight instead of curved, so that, while they permitted communication between the internal and external air, they also aided the general effect by the vibration of straight margins.

These being the general points of difference between the common violin and that constructed by Savart, the success of the attempt was soon put to a severe test. M. Lefebvre, the celebrated Parisian violinist, was requested to compare the tone of his best violin with Savart's. The result was, that the old one

was found to have more brilliancy, but the new one more evenness of tone. Savart remarks, that many of the best violins are more insensible to some notes than to others. This he attributes to the circumstance that, through the bad adjustment of the bar, post, &c., the facility of vibrating in accordance with some notes is less than with others; whereas, in his own instrument, freedom and facility of vibration were provided for in every way. When the old violin belonging to Lefebvre, and the new one of Savart, were played alternately in an adjoining apartment, the tones of the two could not be distinguished from each other,—except by a little more sweetness in the new one.

61. This was probably the first attempt to reduce fiddle-making to scientific principles; and the success which attended it ought to encourage similar efforts. Savart made many violins, such as we have described, which had no pretensions to elegance or high finish, but all possessing the desirable qualities which we are in the habit of attributing to the "good old" violins. Should any of our readers be of a mechanical turn, they might construct good violins at the cost of a few shillings, by attention to the main points of difference between the common instruments and those above described,—all of which latter were made by Savart's own hands.

62. In the guitar, the body is deeper than in the violin, and the object of this increase of depth is probably to be found in the naturally weaker tone of the former instrument than of the latter. We may here observe, that the difference observable in the kind of wood employed for the face of a guitar from that which is employed for the other parts, has especial reference to the facility of vibration of the former. The face is made of a soft white wood, cut very thin in the direction of its fibres, in order that it may vibrate more readily; and it is observable that the varnish or French polish, applied to the sides and back of the instrument, is carefully kept from the face, as its presence there would tend to fill up the pores of the wood, and thus give it a rigidity detrimental to its free vibration.

63. We see likewise that the piano-forte is provided with similar means for increasing the intensity of the sounds produced by the vibration of its strings. A very thin surface of wood is placed a few inches distant from the strings, and parallel to them, so that a sheet or stratum of air exists between the sounding-board and the strings. The vibrations of the strings, therefore, are communicated by this stratum of air, and by the solid conductors to which the ends of the strings are attached, to the sounding-board, which presents a large surface,

and thus excites a powerful action on the exterior air. In the musical instrument called the *seraphine*, some of our readers may perhaps have remarked the great change produced in the intensity of the sound, when soft cushions are placed on the sounding-board. A remarkable degree of softness of tone is thus produced; the explanation of which is to be found in the circumstance that the sounding-board cannot communicate the full force of its own vibration to the exterior air, because the cushions, being almost non-vibrating, are an obstacle between the board and the air.

64. Professor Wheatstone, who may be regarded as the the English Savart in the science of sound, has made the sounding-board of a piano-forte, and of other instruments, the means of producing a most remarkable instance of the transference of sound from one body to another. He prepared a series of connected deal rods; which series was forty feet in length, and was so suspended as to extend, in a straight line, obliquely from an open window of the cupola of the theatre at the Royal Institution, to within a short distance of the floor of the room. On the upper end of this wooden conductor, an assistant placed the stem of a vibrating tuning-fork: when no sounding-board was placed at the lower extremity of the conductor, no sound was heard; but it became powerfully audible the instant the communication with the sounding-board was made: this experiment was repeated with different acute and grave-toned tuning-forks, employed both in combination and in succession.

65. Professor Wheatstone remarks, " The vibration of the sounding-board of any stringed instrument may be communicated in the same manner as those of a string, or of a tuning-fork, to a distant sounding-board, by means of a metallic, glass, or wooden conductor: but in this case, it is necessary to prevent the original sounds from being heard through the air, otherwise the communicated sounds will not be distinguishable from them. This may be effected by placing the originally vibrating, and the reciprocating instruments in different rooms, and allowing the conductor to pass through the floor or wall separating the two rooms.

" In the passage of the conducting-rod or wire through these partitions, care must be taken to prevent its touching their sides; for this purpose a tin tube, covered at its two ends with leather, or India rubber, may be inserted in the partition, and the conductor be made to pass through holes in these coverings, so as not to touch the sides of the tubes.

" A square piano-forte is a very convenient instrument to

employ in these experiments. If the sound is to be transmitted upwards; nothing more is requisite than to open or remove the lid of the instrument, and to allow the conductor to rest upon the sounding-board. A metallic wire is not sufficiently rigid to support itself thus without bending; a rod of some straight-fibred wood, such as lance-wood or deal, is therefore better adapted for this form of the experiment; the lower end of the rod must be reduced in thickness, so as to allow it to pass between two adjacent strings; and the best place to make the contact will be found to be about a quarter of an inch from the bridge, among the middle notes, and on the side occupied by the unvibrating portion of the strings. The reciprocating instrument in the room above, may be a guitar, or any other similar instrument, or a harp; in which latter case, the rod may be brought in contact with the inner surface of the belly of the instrument, through one of the apertures of the swell. These were the forms under which the experiments have been repeated at the Royal Institution."—*Journal R. Inst.*, 1831, p. 229.

66. By these, and other ingenious arrangements, Mr. Wheatstone made a greatly varied series of experiments. He has even communicated the peculiar tone of a clarionet to the sounding-board of a piano-forte, by attaching a solid conductor to the reed or tongue of the clarionet. But perhaps the most remarkable instance of reciprocation, is when a sounding-board is placed in a convenient position near a full orchestra of instruments, with which board is to be connected the conducting-rod, the other end of which is brought into contact with the reciprocating instrument, such as the sounding-board of a piano-forte or guitar, &c. With reference to the effect produced by such an arrangement, Mr. Wheatstone remarks, "On placing the ear close to the reciprocating instrument, a diminutive band is heard, in which all the instruments preserve their distinctive qualities; and the pianos and fortes, the crescendos and diminuendos, their relative contrasts. Compared with an ordinary band, heard through the air, the effect is as a landscape seen in miniature beauty through a concave lens, as compared with the same scene viewed by the ordinary vision through a murky atmosphere."

67. From all this we see the great effect of sounding-boards in modifying or transferring, as the case may be, sounds produced by a vibrating body. This is practically illustrated whenever a tuning-fork is employed. When we excite it to vibrate in the usual manner, the sound is but very feebly heard; but when we place the handle against a table, or against the body of a violin, guitar, &c., the sound is greatly augmented.

This, as has been before shown, is due to the large surface which the sounding-board presents to the air, compared to that which is presented by the tuning-fork.

68. When we contrast a drum with a tambourine of equal diameter, we cannot fail to notice the greater body of sound produced from the former than from the latter. This difference must be attributed to three sources; 1st, the wooden cylinder; 2nd, the second membrane at the other end of the cylinder; and 3rd, the mass of air, enclosed between the membranes, communicating by means of apertures with the exterior air. Any vibration, therefore, excited in the membrane at one end of the drum is communicated both to the wooden cylinder, and to the bulk of air, and through both of those conductors to the other membrane. Thus four parts of the instrument are set into a vibratory state at the same time, and the effect of that combination, is a great augmentation of sound *.

69. M. Biot has remarked, that the orchestras in the Italian theatres are constructed with especial reference to the advantage derived from the employment of a sounding-board or reciprocating surface. The floor, on which the musicians are placed, is situated over a hollow vault; the floor is in fact, suspended in the air; for the points of support are as few as possible, in order that the floor may have an elastic and vibrating power. The vibrations of all the musical instruments are communicated to this elastic floor, and from that to the mass of air included between the floor and the original floor of the building. Thus, a double source of augmentation is obtained; *i. e.* the solid but elastic floor, and the aërial mass beneath it. These artificial aids to the efforts of the performer do not appear to be well understood in the musical arrangements of this country.

70. There is a mode of damping or subduing the intensity of a sound, which is familiar to the violin-player; it is to place on the bridge of the violin, a metal instrument, called a *Sourdine*, (from the French *sourd*, deaf or dull,) which clasps the fibres of the wood closer together, and prevents them from vibrating with that freedom which they would otherwise possess. The effect of this operation on the tone is very remarkable; a stifled, sub-

* Double drums, such as are employed in orchestras, are tuned by means of screws which tighten the head, to the key-note, and the fourth below. A decided improvement, recently patented, has been introduced through the ingenuity of Mr. Cornelius Ward, whereby the drum is tuned with such rapidity by means of a lever acting upon several hooks connected with the hoop upon which the skin is strained, that a tune such as "God save the Queen," may be performed on a single drum, and in a time not much slower than that usually adopted.

duced sound results:—thus showing, that not only does vibration produce sound, but that in proportion as those vibrations are freely communicated to, and shared by, other bodies, so does the effect of the sound increase. It is a frequent remark among the players of musical instruments, that if they sit on a sofa while playing, the effect is not so favourable as if they sit on a firm, solid seat. This has sometimes been attributed to the stifling of echoes, which the non-vibrating cushion of the sofa is calculated to produce; but an apartment fifty or sixty feet in length is required, for an echo to have any appreciable effect; or if there be an effect in a smaller apartment, it is not so much to the stifling of the echo that the unfavourable effect of the sofa is to be attributed, but to the circumstance that the sofa is a non-vibrating substance,—owing to which it not only fails to assist the vibration of the surrounding air, but retards and stifles the vibrations already existing, in a manner analogous to the cushion employed with the seraphine.

71. A very remarkable instance of change in the character of sounds, is produced by breathing gases different from those which compose the atmosphere. In some cases, as with the nitrous oxide, the effect is shown principally upon the brain, by which the person becomes, for a time, deprived of the proper use of his faculties, and performs antics altogether foreign to his inclination in sober moments. These experiments have often been made in public assemblies, and our readers will call them to mind by the name, which has been sometimes applied to the gas, of "Laughing-gas." These, however, are not the effects to which we at present allude. It is hydrogen gas which produces the remarkable effects on the voice, to which we wish to draw attention. If a person inhale a portion of this gas and then continue to speak until all the gas is exhaled, a most extraordinary change of voice is heard by any second person; so much so, indeed, that it would be impossible to recognise the voice of a person with whom we may be familiar, when this gas, mingled with atmospheric air, is contained in the lungs. The voice is shrill, squeaking, and cracked, and particularly unmusical. So, also, if a person with this gas in his lungs attempt to produce notes from a wind instrument, such as a flute, the notes are similarly affected; as the voice in the former case.

72. Thus, we see that the vibration of a column of air is not a circumstance which always has the same meaning. The nature and quality of the air or gas is to be taken into the account, as one of the causes which produce variation in different sounds.

73. From the details just given, it will be seen how various are the circumstances, which change or modify the character of sounds. The first grand distinction between sounds we have found to be, that which determines whether they are such as will claim the title of *musical* sounds, or whether they can only be designated as *noises*. Again, we find that sounds, which may be called musical, differ from each other in character, from a variety of causes. The materials of which the sonorous body is made; the shape or form of which the instrument is constructed; the manner in which the performer excites the vibration, or, as it is generally termed, "plays upon the instrument;" the presence of an elastic sounding-board, to augment the vibrations; the size of the apartment in which the instrument is played; the proximity of cushions, curtains, or other non-elastic substances, which stifle or deaden the sound;—these, and many more sources of difference, give all that variety to musical sounds which contributes so largely to the pleasure we feel in listening to them.

74. Suppose, for example, that the male and feeble voice were of exactly the same character:—there cannot be a doubt that the pleasure which singing affords to the hearer, would be less under such circumstances, than that which results from a combination of voices of different character, or *timbre.*

We pass on now to a consideration of the third question.

SECTION III. WHY DO SOUNDS DIFFER IN PITCH?

75. The manner in which we have hitherto viewed the production of musical sounds, does not enable us to answer the question relative to musical pitch, without a further examination of the circumstances under which sound is produced. We must therefore look somewhat more closely at what takes place when we play on a musical instrument.

76. If a violin-player find that any one of his strings yields a note which is too flat to harmonize with the others, he tightens the string by means of the peg to which it is attached, and in proportion as he tightens it, does the pitch of the note increase in elevation. Now, if we consider the effect of tightening the string, we shall find that it is to increase its elasticity, or the tendency to return to its wonted state after disturbance. We find that a guitar-string, for instance, presents greater resistance to the action of the finger when it is screwed up to a high pitch, than when the note which it yields is of a lower pitch. We find likewise, that in drawing a bow across a violin-string,

the facility with which the string yields to the pressure of the bow is greater with a low degree of tension, or a low pitch, than with one which is higher.

77. We may ask, what effect would a greater tendency to return to a state of repose have upon the number of vibrations in a given time? We know from the experience of common life, that a more intense moving power enables the moving body to travel through a given space in a shorter time than if the motive impulse be less energetic. If a cricket-ball be thrown at a wicket, the time that it will take to travel that given distance will depend upon the force with which it is hurled. This, then, being the case, we are justified in concluding that, if a stretched cord be drawn out of its rectilinear position, and suffered to return again to it, the time which it will take to do so will depend mainly on the force with which it tends to that point; because the distance to be travelled we suppose to be the same.

78. Let us now apply this reasoning to a musical string. We know that the reason why a string vibrates at all is, that the fibres, of which it is composed, become strained from their relative position with regard to each other, whenever the cord is drawn out of its rectilinear position; and that the elastic property resident in those fibres both resists the displacement during the act, and finally subdues it when the disturbing power is withdrawn. It follows, likewise, that as this is the case, whether the disturbance be great or small, the manifestation of this resisting power must increase as the disturbing force increases; and, as we do not suppose that the actual distance to which the string is removed from the straight position is larger in the one case than in the other, it follows that the path which the string has to retrace, is equal in length in both cases; so that the increased elasticity can only manifest itself in a greater rapidity of motion.

79. But we likewise find that the sound emitted is higher in pitch in the one case than in the other. From these two circumstances, therefore, we draw these two conclusions: first, that the rapidity of the vibratory action of the string depends on its elastic tension; and, secondly, that an elevation of pitch always accompanies an increase of elastic tension. These three occurrences—the elastic tension, the rapidity of vibration, and the pitch of the note—all, therefore, increase and decrease together; and we may either consider the two latter as joint effects of the former, or the last of the three as the effect of the two former. When, however, we consider that vibration is the immediate cause of sound in every case, we shall find it more consistent to

say, that increase of elastic tension is one of the causes of increased rapidity of vibration, and that different velocities of vibration is the only cause of difference of pitch in the musical sounds resulting from those vibrations. We must now proceed to apply various tests to these statements.

80. If we listen to the sound emitted by a revolving wheel in a manufactory, we shall frequently find that that sound is of a musical character. This character it derives from the circumstance that the spokes proceeding from the axis to the rim, or teeth arranged round the circumference of the wheel, strike the air with equal and equidistant strokes, and thus present a regularly recurring series of sound-producing actions, which we have said is all that is necessary for the production of a musical sound. In such a case as this, we shall find that the faster the wheel revolves, the more elevated does the pitch of the sound become; while on the other hand, when the revolution of the wheel is slower, the sound descends in pitch. We have all remarked the peculiar whining tone which results from the variation in the tension of a violin-string, while the player is tuning it. As he turns the peg to which it is attached, and thus tightens or slackens it, (as the case may be,) the pitch of the sound is continually varying with every change of tension, and thus produces that gradual ascent and descent of tone which has such a singular effect*. This is rigorously due to a change in the rapidity of vibration, occasioned by a change of tension: every time the peg is turned, however small may be the quantity, the string is tightened, because, in fact, a smaller quantity of the string has to reach from end to end, and therefore the fibres must be in a more strained or stretched condition. This straining, as we have said, increases the force with which the string will tend to return to its state of rest, after it has been drawn out of the rectilinear position by the bow: this increase of force increases the rapidity of the vibration; and this latter increase, in its turn, elevates the pitch of the sound. An explanation similar, though reverse, will avail for the descent of pitch.

81. Very careful experiments have been made, both in this country and on the Continent, to determine the law of increase of pitch with increase of velocity of vibration; and the most important result, perhaps, which has been obtained is, that whatever number of vibrations may produce a given musical

* This effect may be imitated by strongly vibrating a glass goblet, half full of water, and during the vibration pouring the water suddenly out of the glass.

note, double that number in the same space of time will produce the octave of that note: four times the number will produce the double octave, and so on. This very important law is followed by valuable results; but it will be seen that we state the law in general terms; *i. e.*, we assume any number for the vibrations producing a given musical sound, and state that the octave to that sound will be due to a rapidity of vibration double of that which produced the lower note. These are general terms, and give us no information as to the absolute number of vibrations in a second necessary to produce a given musical sound. This information must be derived from other sources.

82. The able Savart contrived an apparatus by which a bar was made to revolve on an axis. The bar was nearly of the same size as an oblong opening in a board; across this opening was the axis round which the bar revolved. At every half revolution, the bar coincided with the plane of the board; a small fissure being all that was left between the bar and the surrounding wood. It followed from this arrangement that when the bar was revolving, it drove the particles of air before it, and that when the bar arrived at that part of its revolution in which it coincided with the plane of the board, a portion of the excited air could not pass through the aperture with the bar, and became, therefore, condensed by pressure against the adjacent board. The moment that the bar passed that position, the air regained its wonted state, again to be condensed when another semi-revolution brought the other end of the bar into the place just before occupied by the first end. Thus arose a series of condensations and rarefactions of the air, which succeeded each other as often as the bar approached the plane of the board.

83. With this apparatus it was found that, when the bar revolved three or four times in a second, an indistinct sound was heard, but without possessing any definite character. When the velocity was increased to eight or ten in a second, a low musical note could be appreciated, which increased in pitch as the velocity of revolution increased. It has been usual in this country to say, that at least sixteen vibrations of a sounding body, in a second, are necessary for the production of a sound, to which we could apply the term *musical*. Savart's experiments gave a lower number: but this difference may very likely arise from difference in the sensibility of the ear of those who made the experiments; for it has been well ascertained, especially by the late Dr. Wollaston, that different persons have different powers of appreciating high and low tones; some can

more readily detect the value of a low tone than of one which is of a great elevation of pitch, while others manifest a capability just the reverse. We will, however, assume that the lowest sound, which can be called musical, is due to a velocity of vibration equal to sixteen per second; believing, at the same time, that there is great probability that some ears are capable of appreciating musical sounds due to a slower rate of vibration.

84. The law of the octaves being once understood, it was convenient to assume a standard by which all musical notes could have a numerical value assigned to them: and it was, therefore, agreed, that a rapidity of vibration, equal to only one vibration in a second, should have a musical symbol attached to it, although no sound could be appreciated. This symbol is C; that is, if a sound, resulting from *one* vibration in a second, could be appreciated by the ear, that sound would be called C. Proceeding now in the law of the octaves, we *double* that number to produce the 2nd C, or the octave to the first: and again, we take *four* as the representative of the double octave of the first, and so on. Thus going on in progression, 1, 2, 4, 8, 16, we find that the 5th term of it, or the 5th C, is the lowest note which can be generally appreciated. Pursuing the same progression we get 32, 64, 128, 256, for the next four terms of the series, all of which represent the number of vibrations in a second necessary to produce the note C, in the different octaves. Now when we arrive at 256, we get the middle C of the piano-forte; a note which, on many accounts, may be considered as a mean between the high and low notes of musical instruments. It is the second C on those flutes which have the additional keys, and the lowest C on the violin. We frequently find six-octave piano-fortes, that is, in which the notes descend to the third A below the note which we have spoken of above, and ascend to the second A above that note. Now, if we apply the mode of calculation before alluded to, we find that the lowest C on the piano-forte is the 6th of the progression before given, or that it results from 32 vibrations in a second; the other two Cs between that and the middle C, being represented by 64 and 128. In like manner, ascending from the middle C, we find the two higher Cs to be due to 512 and 1024 vibrations in a second respectively.

85. So much for the octaves of the note C. We must now turn to the intermediate notes which fill up the several octaves. There is a certain succession of notes, which most ears recognise as being musical, and which fill up the interval of an octave by six intermediate steps. To these steps we apply

the symbols D, E, F, G, A, B. No one can assign a reason why he approves of certain sounds in preference to others, to fill up these several stages. If the instrument on which he is playing be so tuned as to give a certain relation between all the eight notes of the octave, he feels a sensation of pleasure at hearing them; but, if they give a different ratio, his ear is unwilling to listen to them, and he strives to obtain a suitable ratio. The ratio of vibrations, producing the several sounds of an octave which the ear appreciates as being correct, is this:—suppose that, whatever be the number of vibrations producing the note C, we represent it by unity, or 1; then will the number, representing the vibration necessary to produce the other 7 notes of the octave, be as follows, $\frac{9}{8}$, $\frac{5}{4}$, $\frac{4}{3}$, $\frac{3}{2}$, $\frac{5}{3}$, $\frac{15}{8}$, 2, a series remarkable for the simplicity of the numbers forming the numerators and denominators: indeed, it has been frequently remarked, that it would scarcely be possible to produce a series of six quantities, all greater than 1 and less than 2, which should consist of simpler numbers. To apply these ratios to the middle C of the piano-forte, we shall get the numbers:

C	D	E	F	G	A	B	C
1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
256	288	320	$341\frac{1}{3}$	384	$416\frac{2}{3}$	480	512

and, in like manner, we might obtain the number for the note of any other octave.

86. This being the case, we must now direct our attention to a circumstance which we have not yet considered. In order to produce a different tone from a violin-string, we have seen that the performer, when tuning the instrument, increases or decreases the tension of the string, by means of the peg at one end of it: this change of tension being followed by a change in the rapidity of vibration, and consequent upon that—a change in the pitch of the note. But when he is performing on the instrument, he adopts a very different mode of obtaining a change of tone. He does not apply his hand to the peg, or exert any stretching force on the string: he presses his finger on the string with sufficient force to bring the string down to the finger-board, and there to fix it while he produces the required note. Now this act of pressing one point of the string down upon the finger-board, has the effect of shortening the vibrating portion of the string. The bow is applied near the bridge, and never between the place occupied by the finger and the nut of the violin; and thus the latter portion is excluded from the vibratory action, by the pressure of the finger, which cuts off the communication between it and the part excited by the bow.

87. Now we find the effect of this to be an elevation in pitch of the note produced; an effect exactly analogous to that produced by increasing the tension of the string. We thus find that a new element enters into the list of those which determine the pitch of a musical note; namely, the relation between the length and thickness of a string. In order, therefore, to form a judgment of the effect which length alone is susceptible of producing on elevation of pitch, we must suppose that experiments are being made on strings of the same material and of equal thickness, but differing in their lengths, with a view to discover the relation between length and pitch.

88. In order to give this experiment a fair trial, it is necessary that the strings be stretched to an equal degree of tension. This being done, we should find that two strings, one of which is double the length of the other, but agreeing with it in thickness and tension, would yield each a note, one being the octave to the other; the shorter string producing the higher tone. If a third string, four times as long as the one, and twice as long as the other, but the same in other respects, be now operated upon, we should find that it would yield a note an octave lower than the one, and two octaves lower than the other.

89. On comparing these results with those which have been detailed as connected with the number of vibrations in a given time, we find a remarkable resemblance. The number of vibrations for any given note is double of that for an octave lower: and the length of string for any given note is double of that for the same note in an adjoining octave higher. But here a difference begins: the number of vibrations for one octave is double of that for the octave next beneath; but the length of string for one octave is double of that for the octave next above: thus the ratio is the same, but taken in an inverse order. If now we take two strings, of which the lengths are as 3 to 2, and if the former yield the note C in any one octave, then will the other yield the note G next above; an interval which, in music, is called a major 5th. If the lengths of the two be as 4 to 3, and the former yield C, then will the other yield F, a major 4th above that note. If the ratio be 5 to 4, the notes will be C and E, forming a major 3rd; if 9 to 8, C and D, (a whole tone:) if 5 to 3, C and A, (a major 6th:) and if 15 to 8, C and B, (a major 7th.)

90. Now, if we compare these ratios with those which have been given as indicating the number of vibrations, we shall find that they are precisely the same numbers taken in an inverse order; which is obtained by reversing the positions of

the numerators and denominators of the several fractions. Thus, if the length of string necessary to produce any given note, such as C, be called 1, that length which will produce the octave above that note will be half the length, or $=\frac{1}{2}$, and it will be seen that if in like manner we reverse the terms of the other fractions, we shall obtain the proper lengths of vibrating chords.

91. We may give a general view of these results, thus:—

Names of sounds in English and German.	C	D	E	F	G	A	B	C
Ditto in French.	ut	ré	mi	fa	sol	la	si	ut
Ratio of vibrations, the lowest being 1.	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Value of the same, expressed decimally.	1	1·125	1·25	1·333	1·5	1·666	1·875	2
Lengths of the cords which yield the notes, the lowest being 1.	1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$
Value of the same, expressed decimally.	1	0·888	0·8	0·75	0·666	0·6	0·533	0·5

92. This is an important law, and connects the lengths and the tones into one series. It teaches us that the vibrations of chords depend for their velocity conjointly on length, thickness, and tension. We may take three strings, all differing from each other in these elements, and yet they shall all yield the same note. This happens when there is such a compensation of forces between the strings that the excess of thickness in one, the excess of tension in another, the excess of length in a third, are counterbalanced, in each case, by a deficiency in one or both of the other qualities. The violin-player practically illustrates the truth of this statement in the act of tuning his violin. If his ear be not sufficiently correct to appreciate a perfect 5th, as the interval between two strings, he places one finger on such a part of the lower string, that the length between the bridge and the nut shall be divided into two parts, the lengths of which are in the ratio of 2 to 1; or the longer of the two is to the whole string in the ratio of 2 to 3. If now the higher string and the shortened string yield the same note, the player considers them to be in tune. This is an instructive case, and it will be worth while to examine it a little more closely. The strings are originally of the same length from bridge to nut, but being different

in thickness, and most probably in tension, the one yields, when in perfect tune, a note which is a major 5th to the other. Now we have seen that the ratio of the vibration, producing two notes having that interval between them, is 3 to 2, reckoning the highest first; and that the ratio of the lengths of string to produce the same interval is the reciprocal of this, or 2 to 3. To produce a note, therefore, on the lower string, which shall be unisonant with that which is yielded by the upper string, the player shortens the effective length of the lower string, by placing his finger according to such a rule, that its new or contracted length is to its whole length as 2 to 3. If now the sounds yielded by the two strings be unisonant, he knows that there will be an interval of a perfect 5th, when the lower one is extended to its full length.

93. This mode of tuning is adopted by those whose ear is not rigidly correct for musical intervals, but who can appreciate two sounds which are unisonant, or of the same pitch. In the guitar the law is the same, though the application of it is different. The interval between the two upper strings is a *fourth;* between the second and third a *third;* between the third and fourth, the fourth and fifth, and the fifth and sixth, each a *fourth.* In order, therefore, to attune the several strings to one another, the performer whose ear cannot measure correct intervals produces unisons between each two consecutive strings. But to do this, the lower one of the two must not be shortened in the ratio of 3 to 2, for this is the ratio for a major fifth, a larger interval than is used between two adjoining strings of the guitar. Four out of the five intervals are fourths; and to obtain those, the lower string is shortened by the pressure of the finger to three-fourths of its former length; because, as we have seen, the lengths of string to produce a note and the fourth above it are in the ratio of 4 to 3. When, therefore, the lower string has been shortened to this extent by the pressure of the finger, if the two strings yield the same note, we may conclude that the interval between them, when each vibrates in its whole length, is a perfect fourth. With respect to the G and B strings of the guitar, as the interval between them is only a major third, we cut off a smaller portion of the lower string than in the former instances. We see in our series that four-fifths is the fraction expressing the length, for the third above a note which is represented by unity or 1, and we, therefore, place the finger at such a point of the lower string that it divides it into two parts, of which one is one-fifth, and the other (the vibrating portion) four-fifths. If

any of our readers will measure the lengths of the vibrating portion of the strings of a guitar, and the lengths when the finger has been placed upon the proper frets for tuning the instrument, they will find that the three lengths are in the ratio of 1, $\frac{3}{4}$, and $\frac{4}{5}$.

94. For example:—we have now before us a Spanish guitar, of which the length of the vibrating parts of the strings is 25 inches. When accurately tuned for playing, the intervals between the strings, beginning from the lowest are, 4th, 4th, 4th, 3rd, 4th. If now we wish to produce unison between the two lowest strings, we place the finger on the lowest of all, or E string, at $6\frac{1}{4}$ inches from the nut; thereby leaving $18\frac{3}{4}$ inches as the vibrating length of the lowest string: while the length of the other, or A string, is 25 inches, it will be found that 25 bears the same proportion to $18\frac{3}{4}$ as 1 bears to $\frac{3}{4}$; and this is the sense in which we use the latter number. In like manner to make the A and D strings in unison with each other, or the D and G, or the B and E strings, the lower of the two must, in each case, have $6\frac{1}{4}$ inches cut off from its effective length, by the pressure of the finger. As the interval between the G and B strings is only a third, in order to produce unison between them, we find that the G string must be pressed at 5 inches from the nut, by which 20 inches is the effective length. Now 25 is to 20 as 1 is to $\frac{4}{5}$ths, and thus arises the ratio between the two lengths.

95. We thus see that, in performing on the violin or guitar, each string is made to yield a great number of notes, not by varying its thickness, or its tension, but by varying the length of the vibrating portion of the string. In the violin, habit teaches the player at what part of the string he must place his finger, in order to produce the requisite shortening of the vibrating part: but, in the guitar, raised projections, or frets, are placed at the proper intervals, so that, if the player attach a name to each fret, he can always determine the proper aliquot parts of the string.

96. In the piano-forte or harp, however, the case is different: when once the strings are attuned to a proper pitch, no other change is attempted: each string has its proper note and retains it throughout the performance, and therefore we must have as many strings as there are notes to be produced*. The

* The general construction of harps is, we believe, such as to admit of a variation of the tones of a few of the principal strings during performance; whereby, by pressing down one or more of a series of pedals, such a variation is induced on the string connected with such pedal, as to alter the note a semitone.

difference between a piano-forte, harp, violin, and guitar, among themselves, is, in this respect, analogous to that between an organ and a flute; in the former, each note has its particular pipe, which is employed at the proper parts of the performance; while the latter presents the same tube for all notes, the difference of pitch being brought about by having holes cut in the side of the tube, which thus limits the length of the vibrating column of air, according as one or more of the holes are stopped by the fingers.

97. The adjustment of the strings of a piano-forte is brought about by varying the length, thickness, and the tension. It does not appear that, in practice, any given measure of tension is produced in any given string, but that the thickness of the strings is made to decrease from the low to the high according to a regulation which convenience, rather than mathematical rule, has laid down. When we see in the violin or guitar, the great facility with which a thick string may be made to yield a note unisonant with that of a thinner string, either by increasing its tension by turning the peg, or by reducing its effective length by the pressure of the finger, we shall easily understand that a proper pitch for the string of a piano-forte can easily be produced. If the strings were all of the same thickness, they must greatly vary either in length or tension, to produce the extreme notes of the instrument. By a due admixture, therefore, of variation in length, thickness, and tension, the strings of a piano-forte, or of a harp, are brought into harmony with one another.

98. We have now seen, in what has been stated, that any circumstance which makes a sonorous body increase the velocity of its vibration, will elevate the pitch of the note given out. We may, therefore, apply this test to other musical instruments, and determine whether it remains true for all.

99. When a tambourine or drum is found to yield too flat a tone, the membrane is stretched to a greater degree of tension by means of an apparatus applied to the edges, which draws the fibres from the centre towards the circumference. Now we cannot see that any change takes place in the velocity of the vibration of the membrane; but we infer it by parity of reasoning. We know, for instance, that the act of stretching the membrane must increase the tension, and the ear tells us that the note produced is higher in pitch than that produced with a lower degree of tension; and reasoning from the premises before laid down, we infer that the increase of tension produces an increase in the rate of velocity of vibration; while at the same time we are justified (by what has been before

shown,) in inferring, that the elevation of pitch, which the ear detects, is due to an increase of the velocity of vibration. Thus do we arrive at the conclusion, that the membrane of the tambourine vibrates more rapidly, when the tension is greater, than it did before. The tambourine and drum, from the nature of their construction, do not admit of the variation of tone which the majority of instruments can produce. The membrane cannot be thickened, nor altered in size, nor divided into separate vibrating portions, during the progress of a piece of music; and must, therefore, be used for the production of but one note: the rhythm and the intensity of which constitute the objects of the player's attention. These remarks, as far as the drum is concerned, will fail to apply, when Mr. Ward's drums are universally adopted.

100. If we listen to the notes of a concert-flute, and to those of an octave-flute, we shall perceive a striking difference between them. The lowest, D for instance, is of a much shriller character in the latter than in the former: in fact, it is nearly the same sound as the middle D of the concert-flute. Now, when we look at the difference perceptible between them, we see that the material is the same; the general form is the same, the ratio between the distances of the several finger-holes from each other is the same in each,—and the ratio between the diameter of the bore and the length, is about the same in each. The only condition, therefore, to which we can look as the probable source of the difference of pitch in the two instruments, is the absolute length of each. We find accordingly, that the length of a concert-flute, from the cork to the remote end, is about double the length of an octave-flute. When all the finger-holes are stopped in each instance, there is a column of air equal in length to the whole length of the bore, and as the note produced is, in one case, an octave higher than in the other, and as the column of air producing the lower tone is twice the length of that which produces the higher tone; we come to the conclusion that the same principle is involved as was shown in the case of the vibrating string, viz., that the length of the tube, or column of air, varies in the same ratio as the number of vibrations producing the musical sounds, but in an inverse order. As the distances of the finger-holes bear the same proportion to the length of the tube in the large flute, as in the small one, it follows, that the column of air to produce any other note, G for instance, is double the length in the large flute to that which it is in the octave-flute. There are often flutes called *third* flutes, in which the lowest D is a third higher

than the lowest D in the concert-flute; and every other note differs from the corresponding note of the other flute in an equal proportion. It will likewise be found, as in the former case, that the entire length of the column of air in the flute bears the same ratio, in an inverse order, to the length of the column of air in the larger flute.

101. The same train of reasoning applies to the pipes of an organ, and to that familiar and miniature representation of it—the pan-pipes, or common mouth-organ. In each instance there are tubes containing air, which air is set into a state of vibration, in one case by bellows, and in the other by the mouth. The pipes, intended to emit the most acute sounds, are the smallest in length, in order that the vibrating column of air may be enabled to perform a greater number of vibrations in its whole length in a given time; while those sounds which are due to a slower rate of vibration, are produced from the pipes in which the impulse producing the vibration shall have a greater distance to travel from end to end, thus exciting a smaller number of whole vibrations in a given time.

102. If we consider the arrangement of the little tongues or springs in a musical snuff-box, we find the same law to hold good, viz., that those tongues which are to produce the highest tones are shorter than the others. The tongues, as we know, consist of narrow slips of steel, fixed at one end, and free to vibrate at the other. A barrel revolves near the ends of all the tongues, but were it not for little pins or projections inserted into the convex surface of the barrel, the tongues would be untouched by it. Those pins, however, are just long enough to come in contact with the ends of the spring-tongues and bend them upwards. When the pin has left its hold of any tongue, the latter rebounds to its former position, and thus commences a series of vibrations such as we have before described. The tongues are made to harmonize with each other in proper order, before the barrel is brought near to them; and the pins are so arranged on the barrel that any given note may be produced (by touching its proper tongue) according to the progress of the tune or air which may be the subject of the performance.

103. The ratio of the lengths of these tongues offers a remarkable exception to the law which regulates a column of air, and a stretched cord. We have said that the length to produce the octave to any given note, must be half of that which produces the given note: for example, if a length of two feet produces a given note, the octave above that note is produced by a length of one foot; and the octave below it by a

length of four feet. But with metallic bodies the law is different. The nature of a stretched cord is such, that it requires two points of fixture in order to retain a rectilinear position: but a metallic rod, or tongue, requires fixing at but one end; while the end most remote from that is the point which vibrates with the greatest energy.

104. Suppose now that we have two metallic tongues equal in material, in width, and in thickness, fixed at one end, but free to vibrate at the other. If they were of equal length, they would perform an equal number of vibrations in a given time—analogous to the case of other bodies. But, if one be twice as long as the other, the shorter would perform four times as many vibrations in a given time as the longer one: if one were three times the length of the other, the shorter would vibrate nine times as quickly as the longer: if the lengths were as 4 to 1, the vibrations would be in the ratio of 16 to 1, and so on. We thus see that the vibrations do not increase inversely as the length, but as the square of the length: thus, in two strings, if the ratio of length be 2 to 1, the ratio of vibrations is 1 to 2; if it be 3 to 1, the vibrations are 1 to 3, and so on:—but if two metallic tongues be as 2 to 1 in length, the vibrations are as 1 to the square of 2, or 1 to 4; if the lengths be as 3 to 1, the vibrations are as 1 to the square of 3, or 1 to 9, and so on. It follows, therefore, from this law that the vibrating metallic tongues may approach much nearer to each other in length, than may the strings of a musical instrument. It is from the operation of this law that a musical snuff-box is enabled to have such a wide range of notes within such a small space; for, if the tongues had to be varied in thickness or length, in the same ratio as musical strings, some of the tongues would have to be inconveniently slender, or others inconveniently long. In practice, however, the ratio of which we speak is not strictly observed: the steel tongues are not of the same thickness throughout, and the graver notes produced by the longer tongues are made still more grave by the tongues having solid lumps of metal soldered to their under surfaces, and graduated, or so adjusted, as to produce base notes accurately attuned to the upper notes.

105. It is to this class of vibrating bodies that we must assign the *tuning-fork*. It consists, as we have already said, of two vibrating tongues, each of which is fixed at one end and free to vibrate at the other. Now a very small difference, either in length or in thickness, is sufficient to produce a con-

siderable difference in the velocity of vibration, and, consequently, in the pitch of the note produced. If the fork be too flat in tone, a slight diminution of its length will bring it to the proper pitch, by increasing the velocity of the vibration. We may illustrate this in a familiar way by means of a common pin. Fix the pin closely between pincers or in a vice, and vibrate the portion which is exterior to the pincers or vice by striking or bending it with the finger, as we should the tongue of a Jew's harp: we shall find that a clear musical note is elicited,—audible to the performer, but perhaps not so to a by-stander. Let us now vary the length of the vibrating part, by thrusting a greater or less portion within the vice or pincers: we shall find that, as the vibrating portion diminishes in length, the sound becomes more acute; while it acquires a grave pitch, if the length be increased.

106. This property of metallic vibrating slips, by virtue of which they increase their vibration as the square of the length decreases, gives them a great range of compass for musical instruments; and as the sound produced by these tongues or slips is of a very pure quality, we doubt not that they will ultimately be more extensively employed than they are at present, as the sound-producing parts of musical instruments. Indeed, about twenty-five years ago, an instrument on a similar principle to this was constructed by M. Dietz, in Germany. It was called the *Melodian*, and embraced five octaves, of which the tones were produced by the vibration of metallic rods, all of one material, but of unequal lengths,—fixed at one end, but free at the other. The vibratory motion was communicated to them by a metallic cylinder or wheel, to which a revolving motion was given by the performer, with a pedal. The surface of the cylinder was not applied against the rod; but each rod carried at its free extremity, and at right angles to its direction, a narrow and thin plate of copper screwed to it, the surface of which was covered with a small piece of felt impregnated with colophane. This small band being placed near the circumference of the revolving cylinder, was made to descend by touching the key which belonged to it, till it came into contact with the revolving cylinder, and yielded its appropriate sound. The sound continued as long as the plate of copper was pressed against the cylinder; and the intensity of the sound was increased or diminished, by increasing or diminishing the velocity of the motion of the cylinder. The moment the finger was removed from the key, the plate of copper was removed from the cylinder, and settled upon a soft body or

damper, which brought the vibrations, and consequently the sound, to a sudden termination.

107. By these several steps, then, do we arrive at the means for answering our third question. But first, it may be useful to review, in brief, the conclusions to which we have already arrived in the three sections of this article. We have seen that, in order to produce sound, there must be some material substance in a state of vibration, and that those vibrations must be communicated to the ear by the atmosphere, or other medium in which the ear may be immersed; and that, when that is performed, we experience the sensation of *sound*. In the next place, the greatly varied kinds of sound may be divided, as we have seen, into two broadly marked classes, one of which is appreciated by the ear as being *musical*, while the other is deficient in the power of exciting that pleasurable emotion which we experience in listening to musical sounds. We have seen that this division results from the simple circumstance of one kind of sound being due to vibrations which are *equal-timed*, while the other kind is wanting in that isochronism; the vibrations being at one time rapid, and at another time slow, and the gradations between the two not being regulated by any given rule. If we regard a group of soldiers assembled confusedly, and afterwards behold them in the symmetrical order which they observe when on duty, we instantly acknowledge that the latter situation affords more satisfaction to the eye. There is a gratification experienced, which the spectator may be unable to analyze, but which seems to arise from a love of the recurrence, at regular intervals, of similar impressions—whether the ear or the eye be the medium by which those impressions are communicated to the mind. This was the view which the late Dr. Young took of the source of the pleasures which the mind experiences in listening to musical sounds. Any substance, such as lead, which performs its vibrations irregularly, does not afford that amount of pleasure to the mind which a substance of the same shape, but composed of copper, or steel, &c., would produce; principally, because the isochronism of vibration is less observable in one case than in the other.

108. In extending this inquiry to the causes of difference of pitch in musical notes, we find that it results from the ratio between the number of vibrations performed by two or more bodies in a given time. The unit of time, by which these numbers are measured, is a second; but any other might be assumed without vitiating the correctness of the conclusion,

although a second of time is found more convenient than a longer period, on account of the great velocity of the vibrations producing a musical note. The lowest note of a piano-forte may be due to a rapidity of about 30 vibrations in a second, while we have seen that the number to produce the highest note may amount to nearly 2000. But this is far less than might be obtained by a more favourable arrangement of apparatus. The probable reason why the upper notes of a piano are so feeble is, not that the vibrations are so rapid, but that their extent is so small. For it is necessary to bear in mind, that the cause of loudness or intensity of sound, is not to be found in the rapidity of the vibration, but in the extent of space which those vibrations occupy. It is for this reason that the sound of a large drum can be propagated to so great a distance. The surface of the drum is large; and from the peculiarity of the substance of which the vibrating body is formed, it is susceptible of a very wide sphere of vibration; by which it transfers its impulse to a very large number of particles of air, and urges those particles to a great distance, on account of the extent of displacement which the membrane is susceptible of undergoing, and by which the adjacent air is affected.

109. We have traced the operation of the beautiful law, that "the rapidity of vibration, necessary to produce a musical note, must be double that necessary to produce a note an octave lower, and only half as great as for a note an octave above it; and that the intervening notes of the octave depend severally upon numbers of vibrations, which form a very simple series or ratio among themselves." There is also the law, as simple as that above, by which "the lengths of two or more stretched strings, or of two or more columns of air, have to one another the inverse ratio of the number of vibrations, in order to produce the resulting notes;"—thus affording the means of deducing one series from the other. The exception to this law, presented by metallic rods or bars, fixed at one end only, is well worthy of our notice, and presents another of those numerous instances in which one element or one function varies, either directly or inversely, as the square of another.

110. We are now, therefore, enabled to obtain an answer to our third question, "What is the cause of difference of pitch in different sounds?" The cause is, a variation in the number of vibrations which the sound-producing body makes in a given time, without reference to the material, the form, or the mode of excitation of the vibrating body:—these latter conditions producing modifications in other respects, but not interfering

with the law that, "increased velocity of vibration produces elevation of pitch."

Section IV. Why is the Tuning-fork employed as a Standard of Pitch?

111. The reader may sometimes have made it a matter of speculation, why a tuning-fork should be preferred to any other body, (such, for instance, as a cord of cat-gut,) as a standard whereby to regulate musical instruments.

112. The solution of this inquiry may be found in the circumstance, that metal is not so liable to be affected by extraneous causes, as animal membrane. A piece of steel is of a very close texture, and resists the entrance of moisture between its particles; but a membrane, such as a string of cat-gut, or the head of a drum, is peculiarly liable to be affected by the hygrometrical state of the air, as is shown in several places, under the article Hygrometer. We have often experienced, and we doubt not many of our readers have likewise, the annoyance of finding the strings of a guitar, woefully out of tune, although they were a short time before, correctly tuned to each other. This is occasioned by the absorption, or by the loss, as the case may be, of a portion of moisture on the part of the strings, by which their tension is varied. Now, if the variation were equal among all the strings, the pitch of the whole instrument might be raised or lowered, without rendering them inharmonious one with the other. But some of the strings are thicker than others; and some are shielded by silvered wire, while others are exposed to the atmosphere: it follows, therefore, that an equal ratio of moisture is not absorbed, or lost, by all the strings, and that they are not only raised or lowered in pitch, but that this raising or lowering is more effective with one than with another.

113. The same thing happens to a piano-forte, a harp, or a violin. The strings alter their tension by changes either in the moisture or in the temperature of the air, and thus give out a different series of sounds from what they produced a short time previously.

114. It is worthy of remark, likewise, that the tone produced from a wind-instrument, is not always the same. The manner in which the player applies his mouth to the instrument, has an influence in raising or depressing the pitch of the tone. This is particularly observable in the flute, where the upper lip partially covers the *embouchere*, or mouth-hole. Two flute-players will

attune their flutes, so as to agree in pitch, and to enable them to play a duet with the requisite correctness; but if they exchange flutes, it frequently happens that discord arises immediately. This is occasioned by one player producing uniformly sharper notes on the flute than the other, either in consequence of varying the aperture between the lips, the force of the blast, or the extent to which the upper lip covers the hole. We have repeatedly known this to occur in practice, and could always trace it to one or other of these causes.

115. A very pleasing confirmation of this statement is obtained by employing a flute and a tuning-fork in the following manner. Fix a little circular disk of paper or pasteboard, or even a wafer, about half an inch in diameter, on the face of one of the prongs of the tuning-fork, near the extreme end. Then take a concert-flute, and finger it as if about to produce the note yielded by the tuning-fork, but without blowing into the flute; if, for instance, it be a C fork, finger the flute for the note C. Then, having vibrated the tuning-fork, apply the disk which is on one of its prongs, to the mouth-hole of the flute, so as nearly to cover the hole. The sound of the tuning-fork will be found to be augmented in a slight degree by this process. But the augmentation may be increased by altering the note yielded by the flute. If, for instance, the flute have a sliding tube, draw out the tube an inch or more, and finger the flute for C as before; the tone will now really be B, a semitone lower than the former. If, however, the flute have not a sliding tube, finger it for B, instead of C. In either of these cases, apply the vibrating disk as before, and the sound of the fork will be found to be very considerably louder than in the former case.

116. To explain this, we must understand that, when the vibrating disk is held over the mouth-hole of the flute, the column of air contained within the flute is set into a state of vibration, because it is in communication with the film of air immediately adjacent to the disk. This column of air is of the exact length to vibrate isochronously with the disk; that is, if the disk make 100 vibrations in a second, the column of air, by the arrangement of the finger-holes, &c., is of that length which will likewise give 100 vibrations in a second. We have, therefore, two musical instruments instead of one, playing at the same time; and thus the sound is augmented.

117. But this, taken in the simple sense in which we have viewed it, would lead to the conclusion that, when the flute is fingered, so as to produce the precise note yielded by the fork which has the disk, the augmentation of sound would be more

decided than when the two instruments were discordantly arranged; whereas, we have said, that when the fork yields C, and the flute is fingered for B, the united sound is louder than under any other condition of the question.

118. This apparent contradiction arises from the depression of tone, which the lips produce in a flute; the tone of a flute is really C, or a fraction of a semi-tone less than C, at the time that the player, by the influence of his mouth, produces the note B;—the proper length of the column of air is such as to produce C; but the mechanism by which the player elicits the note changes that note to B. Hence we finger the flute for B, in order to gain the doubly sonorous effect of C, by means of the tuning-fork.

119. The effects, produced by holding a vibrating tuning-fork over the mouth-hole of a flute, have been extended by Professor Wheatstone to other tubes, such as those of a common mouth-organ. He adapted a moveable piston to a tube, so as to vary its effective length, and found that the intensity of the sound yielded by a vibrating tuning-fork was increased, when the vibrating prong was held over the tube. The amount of the increase depends on the relation between the effective length of the tube, as regulated by the piston, and the pitch of the tuning-fork.

120. At one of the meetings of the British Association, Mr. Addams communicated the result of an experiment, which he had performed on two tubes placed at right angles with each other, and of the same length and bore. The edges of the open ends of the two tubes were placed in contact; but one tube was perpendicular to the other. A tuning-fork was then vibrated, and held close to the openings of both tubes, so as to act equally upon the column of air in each. It was found that the vibrations of the column of air in one tube interfered with, and stifled, those excited in the other; so that the sound yielded by the fork was no more augmented than if no tube had been present. That the interference of the vibrations of the two tubes, by being at right angles to each other, was the cause of this non-increase of sound, was shown by the fact that, when one of the tubes was turned a little round, so as to be removed from contact with the other tube, the sound was augmented, as is generally the case with a single tube.

121. We may here allude to another instance of *interference* shown by the tuning-fork, which was, we believe, first described by the late Dr. Young. When a tuning-fork is vibrated in the usual manner, and then held up in a vertical

position, at a short distance from the ear, it will be found that the sound is not equal in intensity when different parts of the fork are presented to the ear. If we turn the fork round on its axis, we shall perceive eight alternations, or variations, of intensity during one revolution of the fork.

122. When the broad surface of either prong is nearest to the ear, the sound is of maximum intensity. When the edges are towards the ear, the sound is nearly, or quite as loud: but when the fork is held, so that neither face nor edge, but a corner of one of the prongs, is immediately opposite the ear, the sound is much weaker than in the former cases. In all these instances the fork must be held parallel with the ear.

123. The reason of this is to be found in the circumstance that the vibrations produced in one direction interfere with those in another. When the tuning-fork is vibrated, the prongs alternately approach and recede from each other. When they approach each other, the air on the outer surface follows them inwards, while the air between them is forced outwards at the edges; so that the air in two directions is travelling towards the fork at the same time that the air in two other directions, at right angles to the former, is travelling outwards or from the fork. There must, then, obviously be four points where the ingressing and the egressing masses of air meet each other; and at those points a certain degree of compensation or interference occurs, by which the intensity of the sound is deadened.

124. Sir J. Herschel illustrates this interference by referring to the effect produced by closing and shutting the hands near the flame of a candle. If we place the palms of the two hands together, the edges being towards a candle, and then alternately open and close them by a waving motion to and fro, the flame will be blown alternately to and from the hands. In such a case, the undulations excited in the air by the hands are communicated to the candle. But if the hands be held obliquely towards the candle, the disturbance of the flame will be less conspicuous; because the motion produced by the broad surface of the hand is counteracted by that which results from the air which is pressed out from beneath the hands.

125. Professor Wheatstone has given a curious illustration of what he considers to be the *polarization* of sound: by which he means a *stifling* or *extinguishing* of sound, when communicated in certain directions. A tuning-fork was employed in performing these experiments, as follows:—He connected a tuning-fork with one extremity of a straight conducting rod, the other

end of which communicated with a sounding-board. On causing the tuning-fork to sound, the vibrations were powerfully transmitted; but on gradually bending the rod, the sound progressively decreased, and was scarcely perceptible when the angle at which the rod was bent was a right angle. As the angle was made more acute, the phenomena were produced in an inverted order; the intensity of the sound gradually increased, as it had before diminished; and when the two parts were nearly parallel, it became as powerful as it was when the rod was straight. By multiplying the right angles on a rod, the transmission of the vibration may be completely stopped.

126. There are but very few individuals, whose voices are so much under the guidance of their musical ear as to give a note rigorously correct at all times, without the aid of a musical instrument. We frequently hear that the best singers are, at times, out of tune; and this circumstance would effectually prevent the voice from being taken as an unvarying standard of musical pitch.

127. The objections made to the different sounding bodies which we have enumerated above, do not apply to the tuning-fork. The material of which it is composed, and the manner in which it is formed, save it from those objections, and render it a very useful little instrument. Forks are made of various degrees of pitch, and tuned with sufficient accuracy for ordinary circumstances. Some, however, to which the term *Philharmonic* has been attached, are rigidly correct, their pitch having been tested by the standard adopted by the Philharmonic Society.

128. Thus have we endeavoured to present to the reader an outline of the principles which are involved in the production of the sounds of a tuning-fork. It may appear singular that we should devote so considerable a space to what appears but a simple and unimportant instrument; but we are among those who think that the term "insignificant," or "unimportant," is often greatly misapplied. We are all too much in the habit of being attracted by the prominent and conspicuous objects and events which present themselves to our notice, and to fancy that that which is simple and unobtrusive does not present claims to our attention. The fact, however, is, that those philosophers who have the greatest power of mind, are precisely those who can best appreciate the value of seemingly unimportant or trivial occurrences. This should teach us to be cautious how we deem small subjects to be beneath the majesty of the mind.

VIII.

HARMONICA, OR MUSICAL GLASSES.

How soft that music!
Falling at intervals upon the ear
In cadence sweet, now dying all away,
Now pealing loud again, and louder still,
Clear and sonorous, as the gale comes on!
With easy force it opens all the cells
Where Memory slept.—COWPER.

1. IF we were to enumerate all the instances in which a fear of too great an expense puts an unfortunate check to any attempt to avail ourselves of rational pleasures otherwise desirable, we should find that a great number of them is occasioned by a very erroneous impression of the difficulties to be overcome. By the exercise of a little reflection and ingenuity, we might greatly enlarge the scope of our pleasures,—pleasures every way removed from all that is gross and debasing,—with an outlay which comes within the means of large classes of society, who, at present, consider themselves to be shut out from such enjoyment.

Among the sources of pleasurable enjoyment, are *Musical Glasses*, an assemblage of which forms an instrument which appeals to the feelings in a manner which few other musical instruments can equal: the liquid sweetness, the roundness of volume, the swelling crescendo and plaintive diminuendo effects, together with the thrilling intensity of the tones elicited from these glasses, are such as no one with a spark of musical feeling can be indifferent to; and yet, this instrument is almost excluded from the social circle, except in the more wealthy classes: those even moving in the middle ranks of life are deterred from incurring the expense of it; but it will be seen that this is not necessarily the case. A tolerably correct musical ear, and a little ingenuity, will be sufficient, at a few shillings' expense, to bring this pleasure within the reach of most domestic circles, and to add one to the many sources of enjoyments which are appreciated better in this than in any other country, (except Germany,) by the name of "fire-side amusements;" and those well-wishers to mankind, who strive to elevate the tone of moral feeling, and to bring out all the better and more ennobling traits

of the mind, well know how to value any endeavour which has the effect of increasing the charms of domestic society, and to render more endearing and attractive the associations which so irresistibly steal over us, when connected with the word "home."

We propose, therefore, to request the reader's attention to this subject, which we can do with the greater propriety, because the previous paper, on the "Tuning-fork," will have prepared us for the consideration of musical glasses. We shall likewise be enabled to present to the reader what we hope will be considered a novel series of experiments, on the modes in which glass and other vessels perform their sonorous vibrations.

2. It will be found convenient to divide the subject of the present article into three sections, as follow :—

i. A detail of the principal modes in which Harmonica have hitherto been constructed, and a description of an easy and economical plan for forming them, which the writer has found to be well adapted to the purpose.

ii. An inquiry into the scientific principles which regulate the vibration, and the musical character, of circular vessels of glass, generally.

iii. An extension of this inquiry to circular vessels formed of other material; and to the modifications which a deviation from the circular form produces on the tones elicited.

Section I. The Harmonica.

3. The first mention which we have of glass vessels being employed as musical instruments, is found in a letter written by Dr. Franklin to Father Beccaria. The Doctor calls them *armonica*, from the Greek word for *harmony**. We will give a short portion of the letter in Franklin's own words, as they are very characteristic of the subject.

He says, "You have doubtless heard the sweet tone which is drawn from a drinking glass, by pressing a wet finger round its brim. One Mr. Puckeridge, a gentleman from Ireland, was the first who thought of playing tunes formed of these tones: he collected a number of glasses of different sizes,—fixed them near each other on a table,—and tuned them by putting into them water, more or less, as each note required; the tones were brought out by pressing his fingers round their brims. He was unfortunately burnt here, with his instrument, in a fire which

* When the Greek word is Anglicised, the letter *h* is prefixed to compensate for the Greek aspirate.

consumed the house he lived in. Mr. E. Delaval, a most ingenious member of our Royal Society, made one in imitation of it, with a better choice and form of glasses, which was the first I saw or heard. Being charmed with the sweetness of its tones, and the music he produced from it, I wished to see the glasses disposed in a more convenient form, and brought together in a narrower compass, so as to admit of a greater number of tones, and all within reach of hand to a person sitting before the instrument; which I accomplished, after various intermediate trials and less commodious forms both of glasses and construction, in the following manner." Franklin then proceeds to describe his instrument, the construction of which appears to be this:—He had twenty-four glasses blown to a hemispherical shape, and varying from nine inches to three inches in diameter; the tones of these glasses were tested by means of a harpsichord; and when any inaccuracy of tone was observed, the exterior surface was ground down to a greater thinness, whereby the tone was lowered; in order to prevent any of them being *lower* in pitch than was required, he had five or six made nearly of one size, and then ground them down to the proper tones.

The intervals between the tones of the glasses were so arranged that he had three complete octaves. When the requisite accuracy was attained, he arranged the glasses in the following manner:—A box or case was made, three feet long and eleven inches in width, and the same in depth at the larger end, while the width and depth diminished to five inches at the other end. Through the middle of this box, from end to end, proceeded an iron rod, an inch and a half thick at one end, and half an inch at the other, tapering from end to end in the same way as the box which contained it. The bottom of each glass was perforated, and the perforation surrounded by a collar or neck, the diameter of which was one inch and a half in the largest glass, and half an inch in the smallest; into each neck a cork was tightly fitted, through which a hole was bored. The glasses, thus prepared, were then fixed on the iron rod in succession, one in the other's hollow, with the plane of the periphery in a vertical direction. If we suppose twenty-four tea-saucers or basins placed one in the other's hollow, and then turned up on their edges, and a rod passing through them all, it will give some idea of Franklin's arrangement. The glasses were not allowed to touch each other, as the corks were slightly projected to prevent such contact.

The iron rod was not *fixed*, but moved in a gudgeon at one end of the box, while at the other it was connected with a wheel

round which a strap passed, which communicated with a lever moved by the foot: on pressing this lever, then, the rod acquired a rotatory motion, and the glasses, being firmly fixed to the rod, were carried round with it. The exterior surfaces of the glasses being then slightly wetted, and the finger entirely free from grease, each glass, as its particular tone was required, was touched by the finger in the course of the revolution of the rod, and thus the tones were elicited. Franklin says, "To distinguish the glasses more readily to the eye, I have painted the apparent parts of the glasses within-side, every semitone *white*, and the other notes of the octave with the seven prismatic colours; viz., C red, D orange, E yellow, F green, G blue, A indigo, B purple, and C red again, so that the glasses of the same colour (the white excepted) are always octaves to each other."

4. Franklin describes the tones produced from this instrument as being superior in mellifluous sweetness to anything he had ever heard before; but it is obviously an arrangement which is exceedingly liable to disturbance; any want of horizontal precision in fixing the glasses on the rod, and any slight loosening of the contact between the glass, the cork, and the rod, would throw the whole apparatus out of repair; while the expense of it must be enormous; as the Doctor advises that *six* glasses of each size should be formed, in order that the one which approaches most nearly to the required pitch might be selected: thus the number to be made would be nearly 150.

5. Dr. Edmund Cullen, of Dublin, subsequently proposed a modification of this arrangement, apparently not so much in the mode of fixing the glasses, as in the choice of tones and harmonic chords which would be productive of the most pleasing effects; but the objection as to difficulty of construction, and costliness, applies to this as well as to the former construction.

6. It has been proposed to arrange the glasses on a wheel turning rapidly in a horizontal direction. But supposing this to succeed, as far as mechanical arrangement is concerned, every plan of this kind is subject to the serious objection, that wheel-work inevitably creates a *noise*, the effect of which is a sad interference with the melodious strains of the glasses.

Subsequently, however, all wheel-work, and similar machinery, was discarded: the glasses were fixed in double rows upon a horizontal board, and the tones produced by the motion of the wetted finger upon the rim of the glasses, instead of by the stationary finger upon moving glasses.

7. M. Grenié prepared harmonica-glasses in the following manner. Having procured glass vessels of similar forms, and of

dimensions depending upon the pitch of the notes to be produced, he perforates them at the bottom, somewhat after the manner of Franklin, at the part where they are to be fixed on the cylinder. He then procures spherical moulds, and grinds down the glasses upon a turning-lathe, both on the inner and the outer surfaces, until they have as near as can be the same thickness throughout. He then grinds them gradually down on their rims perpendicular to their axes, until, when placed on the cylinder, they give out the exact tone which is required: and so on with all the glasses. The extremely laboured and expensive nature of this process obviously unfits it for popular adaptation.

8. A few years ago, Mr. Tait devised a method of preparing the harmonica, which presented a considerable improvement on previous methods. His glasses are shaped somewhat similarly to a glass sugar-basin, and having been blown respectively to sizes which experience has determined to be nearly fitted for the production of the requisite tones, they are brought to the proper pitch by coating a portion of the surface with a resinous composition, which has the effect of retarding the velocity of the vibrations, and, as a necessary result, lowering the tone. These glasses, thus tuned to the proper pitch, are arranged in a double row in a case fitted for the purpose; the edges of all the glasses are on the same level, and the tone is produced by passing the moist finger round the edge of the glass whose tone is required. This harmonica* is by far the most perfect which has ever been constructed; no friction or grating noise of wheel-work interferes with the melody of tone; and the whole arrangement, whether considered as a source of beautiful musical effects, or merely in its exterior fittings, is a very elegant and delightful ornament to the drawing-room.

But the latter part of this observation brings us at once to the object of this article. The harmonica just described, beautiful and almost perfect as it is, is necessarily attended with an expense so great, that it is utterly unavailable for the *popular* extension which we wish to see attached to this beautiful instrument.

9. An economical mode of attaining this object, with moderate accuracy, has been frequently adopted, thus: the glasses are chosen as nearly as can be of the proper pitch, and the requisite adjustment is made by means of *water*, which, being poured into the glass, lowers the tone: but this is, for many reasons, an

* The word *harmonica* is properly a Greek plural; but we take leave to use it singularly and collectively for the whole apparatus, of which we are speaking.

imperfect mode; the freedom and extent of the vibrations of the glass being retarded by the weight of the water contained in it; besides which, evaporation is constantly going on from the surface of the water, and the relation between the tones of the glasses containing water and of those which do not, is thus constantly changing, and requires very frequent adjustment.

10. Now the mode in which we propose these glasses to be chosen, is one which we first pointed out and practised, and which we know from experience to be available for the purpose. It is to place a great number of soda-water glasses, goblets, and wine-glasses, in a convenient way for ascertaining their tones, (and this may be done at any warehouse where such glasses are sold,) and then to choose the lowest tone which can be selected from among the soda-water glasses; next, ascertain its value, and make it the fundamental, or key-note, to which all the others may be referred. It matters not much what that note is, provided the others be chosen with reference to it. In three different instances, the writer of this article was enabled, in an hour and a half or two hours, to select very accurate and beautiful sets, each set embracing a range of $1\frac{1}{2}$ or 2 octaves. About two or three soda-water glasses, eight or ten goblets of different sizes, and three or four wine-glasses, will, in general, produce two octaves complete, with an additional semitone, in case it may be desired to play in another key. The most useful semitones which could be chosen would be the minor 7th and the minor 14th, above the fundamental note of the series, or those two notes which are respectively half a note below the octave and the double octave to the key-note; these two additional semitones will enable the performer to play in a key a major 4th above the fundamental key of the set.

11. The glasses being thus chosen, (and a moderately correct ear will readily ascertain the relation which the tone of a flute bears to any glass whose tone is being elicited,) may be placed in a box, in any order which may be thought most desirable for facility in playing; and as they will most probably be of unequal heights, the smaller glasses may be elevated on small blocks of wood, so as to bring them all to a level. The foot of the glass may then be secured to the case by means of two or three wooden screws, similar to those used in a swing dressing-glass; the screw being within a quarter of an inch of the foot, the head or nob of the screw will firmly grasp it, and retain it in its place: or instead of screws, buttons may be more conveniently employed, as they allow glasses to be more quickly shifted.

12. Various modes of arranging the glasses have been pro-

posed; but that of Dr. Arnott is, perhaps, the most convenient. He places them in a zig-zag double line; so that, in ascending the series from the lowest to the highest, the finger describes a course analogous to the tacking of a ship in a contrary wind. The advantage of this arrangement is, that all the notes which, in printed music, are on the *lines*, are represented by glasses in one line, while those which occupy the *spaces* are placed in the other line: thus, suppose our fundamental note is the lowest C on the flute; one line of glasses would contain C, E, G, B, D, F, A, C; while the other line would contain (ascending in the same way) D, F, A, C, E, G, B. There is another advantage attending this arrangement: as it is very easy to play with both hands on this instrument, it is desirable that the harmonic thirds, which so continually occur when a duet is played, should be placed in our arrangement as prominently and conspicuously near each other as possible. In Arnott's system they are immediately next each other in the same line; and, therefore, mistake is impossible.

13. Should the choice of the glasses devolve upon one whose musical ear, as it is called, is not always sufficient to assure him when he has attained unison between the flute and any glass, the following plan has been found very available: suppose, for the sake of making our meaning more plain, that the lowest note procured is C : then, in order to get a glass giving out the D note, if the note D be played strongly on the flute, the glass on the table which happens to be in unison with it will sound sympathetically with it, without being itself struck or rubbed by the finger*. This is one of the most beautiful facts in the science of sound: if two bodies, capable of producing sonorous vibrations, have such an elastic tension that they will vibrate in equal times, the sound elicited from either one of them will, when they are placed near each other, excite the vibrations of the other; and this is, perhaps, the most delicate test which we could possibly have of the unison of two tones.

When the D is thus produced, E may be sounded in a similar way; and if the sympathetic note E be heard from any one glass, that glass may at once be selected. These directions apply to all the other notes, and we thus make the sounds themselves

* One of the harmonic notes, a third or a fifth, for example, will also cause the fundamental note to vibrate, and *vice versâ*; but this sympathetic vibration is of a very faint character, and will never be mistaken for the full and decided sympathetic tones produced by the vibration of one body in unison with another sounding body.

assist us in determining that which our own perception is not sufficient to accomplish.

14. Every one conversant with music knows that a very large range of tunes can be played within one octave, and a selection of even eight only, such as we have described, will be found a prolific source of enjoyment; and it will be productive of pleasurable feelings to the minds of all who are alive to the poetry of music, to find that their taste can be gratified from instruments made for a very different purpose, and obtained at so small an expense.

15. A common idea prevails that musical glasses are very difficult to play: this is quite a mistake, for there is no instrument requiring so little skill and attention from the performer. A few hours' practice will enable any one to bring out the tones fully and clearly; and when this skill is attained, the choice and execution of melodies must be left to the taste of the performer, since no further directions can be given. Many suggestions have been made as to the best mode of exciting the vibrations of the glass; but it is doubtful whether any mode is so available and consistent with the object in view as the moistened finger. The learner will find it advantageous to employ water slightly impregnated with alum, with lemon-juice, or a few drops of muriatic acid; but, with a little tact and a little practice, pure water will do perfectly well. It may also be remarked that the tone is best elicited when the middle finger is employed, and this must be moved *from*, and not *towards*, the player: this remark was made by Franklin with reference to his revolving apparatus, and it applies equally to the other systems. The glasses should likewise be frequently sponged, to remove any dust or grease from the edges; and previously to performance, if the learner have ever found it difficult to bring out the tones, the hands should be washed in *warm* water, for the purpose of softening the skin of the fingers; which must be well dried, and then dipped in *cold* water, to produce the tone. A glass of cold water should be contained within the case, as near to the performer as possible. When the apparatus is set aside, the glasses should be protected with a cover from dust and injury.

16. We may here observe, that the perfect character of the tones, producible from glasses, subjects them to a defect which less perfect instruments would render inappreciable; we mean the interference of two tones, which, in musical language, is said to produce discord. Suppose the note G, for instance, to be occasioned by 100 vibrations in a second, and the note A by 108 vibrations; at each of the 100 vibrations the

air between the glass and the ear is thrown into a sort of *wave* of sound, which wave recedes, and is again propelled forward, 100 times in a second; the same air is agitated by the other glass 108 times in a second; therefore, at the beginning of the double vibration, the forward advance of the waves is nearly equal in both cases, but at the end of one second one glass is 8 vibrations in advance of the other: at the end of two seconds it is 16 vibrations in advance: at the end of 3, 4, 5, seconds, it is respectively 24, 32, and 40 vibrations in advance: so that at the end of 6 seconds it is 48 vibrations in advance; or, in other words, the quicker vibrations will have so far gained upon the slower, that the impulse *forward* imparted to the air by one glass, is nearly as strong as the recessive impulse from the other, and the air does not *move at all;* it would be found, therefore, as long as those two notes are sounded together, there would be an interval of *silence* about every six seconds. This repetition of stoppages, or *beats*, as they are called, is the sole cause of the discord which we are sensible of when two adjoining notes in the scale are heard together. In any instrument in which the sound ceases soon after the exciting cause is removed, this inconvenience is not felt; but when the sound, as in musical glasses, continues many seconds after the finger is removed, several successive notes in the same time are lingering in the ear at the same moment. If they happen to be thirds, or fifths, or octaves, the effect is heightened; but if a second, or a seventh, the beat or jarring commences.

17. There is an analogy to this interference afforded in a very familiar phenomenon: when a stone is thrown into a lake or pond, a series of concentric circles of waves or undulations emanate from it: these circles consist of alternate elevations and depressions of the liquid surface. If now another stone be thrown in at a short distance from the first, a similar series will emanate from that also, and the two series will soon meet each other. If it happen that an elevated ridge from one system coincide with an elevated ridge from the other, the result will be an increased elevation; but if a depression from the one meet an elevation from the other, the surface, by the balance of forces, remains at its original level, and no wave exists there. So it is with sound. If two progressive waves coincide, the effect is an increased tone; but if a progressive meet a recessive wave, both are neutralized.

This defect is, however, so small, when brought into comparison with the excellences of the instrument, that we must

not allow it to deprive us of the pleasure derivable from those excellences. In fact, those very excellences are the cause of its defects.

18. Should these few details have the desired effect of extending the range of such musical resources as are available for the large bulk of the community, it will add one to the many instances in which science, if sought out and properly appreciated, conduces quite as much to the pleasures, as to the more solid advantages of society.

We now desire our readers to remove their musical glasses from the music-room to the study; where we will endeavour to investigate the principles by which the vibrations of these vessels are regulated.

Section II. On the Vibration of Glass Vessels.

19. One of the most influential circumstances in retarding and discouraging the practical pursuit of science among the bulk of our fellow-men, is an unfortunate opinion that such investigations necessarily require costly and elaborate apparatus: this opinion has been, in many instances, rather encouraged than discountenanced by selfish labourers in the field of science, who have thought such knowledge to be a patrimony belonging to the few, fearful lest the honour and credit accruing from scientific discovery should, by being shared among many, leave but a small modicum for each. Men, who are themselves bright stars in the intellectual firmament, have thought that, by shining alone, their own brilliancy would be more conspicuous than when lesser stars claim a portion of general admiration. If personal exaltation were the end and aim of science, all this might be well; but, as the advancement and well-being of the whole human family is the ennobling object which guides the inquiries of all rightly constituted minds, we find that this prejudice is gradually wearing away, and that a love of the true and the beautiful, being strengthened by the very search after them, will be a probable result of placing in the hands of the many the means of performing experiments hitherto confined to the few.

One of the chief objects of this volume is to render the delightful field of experiment open to all lovers of nature, and particularly to such as are limited in means, either of a local or of a pecuniary kind. In the 1st section, we endeavoured to show that much melody might be derived from the skilful combination of a few drinking-glasses; and we are now about to

show that much science may be learnt by the judicious employment of similar vessels: hence, we propose to study, in two sections, the laws which regulate the vibration of glass and other vessels. The reader is, therefore, requested to provide himself with two articles, whose usual employments occur at times when people are least disposed to be philosophical; we mean, a common drinking-glass, or goblet, and a fiddle-bow.

20. In order to prepare the general reader to follow the *rationale* of experiments of this kind, it will be advisable to premise a few words in addition to what has been already said in the article on the Tuning-fork, on the acoustical laws which regulate the production of sound.

What are the wonderful bonds of connexion between the tangible material objects which surround us, and the sensations and ideas which those objects engender in the mind, is a mighty subject, which *human* sagacity will most probably never be permitted to penetrate. Physical effects on our sensorial organs are now much better understood than formerly; but how physical effects merge into mental perceptions, we must confess ourselves totally inadequate to explain. All we can say is,

> It is the soul that sees; the outward eyes
> Present the object, but the mind descries.

The last physical link in the chain to which our inquiries and experiments have extended, is the vibration of nervous filaments; how those vibrations give birth to mental phenomena, is a vast and unknown process; but how discouraging soever this limit to our faculties may appear, it should not prevent us from collecting all the information which research may afford, concerning the vibrations themselves, and the changes in our sensations which a given change in the vibrations is known to produce. We cannot tell what *gravitation* is; but we can measure variations in its intensity, brought about by given physical changes; and, in like manner, although we cannot tell what *sensation* is, we can appreciate a difference between two sensations, the result of two physical impulses, which difference is within our power to calculate or to measure.

21. A stretched cord, and a glass goblet, are acted upon so differently by any force applied to them, that a slight analogy is all that can be shown between them. It will, however, be useful to remark, that, when a cord is stretched between two fixed points, and vibrated, the first and simplest method of the vibration is to describe a curve, in its whole length alternately on both sides of the line of repose, or *axis* of the cord, the axis

and the two curves being all in the same plane; this produces the *fundamental tone* of the cord.

22. A more complex mode of vibration is, when there are certain points which never leave the axis, although the rest of the cord is freely vibrating; the relative distances of these points determine the lengths of the included vibrating portions, and those lengths have what is termed an *harmonic ratio*, or *proportion* to each other: the points which do not leave the axis are termed *nodes;* and the portion on one side of any node is on an opposite side of the axis with respect to the other portion during vibration: each portion is termed a *ventral segment*, and its centre a *centre of vibration.* When, therefore, the axis of the cord vibrates, and is at the same time divided into separate portions, which have a certain ratio in their lengths, and vibrate each in a system of its own, the resulting sounds are, *first*, a fundamental note due to the vibration of the cord along its axis, and, *second*, more acute tones due to the separate portions of the cord; and all these tones, by virtue of the ratio above-mentioned, harmonize with each other, the acute tones being termed *harmonics.*

23. This being premised, we may consider it as a constant law, that *when any body emits a musical sound, it is vibrating with great rapidity, and with exactly equal intervals between the vibrations.*

24. Let us now take a common goblet, or drinking-glass, of any kind, and pass the moistened finger round its edge; we shall find a delicate and exquisitely pure musical note result therefrom, and that the note is, generally speaking, higher in pitch when the glass is either small in diameter or thick in substance, than when the opposite conditions occur. We may now ask two questions respecting these results; *first*, In what manner does the glass, being circular, perform its vibrations? and, *second*, Why does a small or a thick glass emit a higher tone than one which is either larger or thinner? The answer to these questions leads us into a field of inquiry, rich in instructive phenomena, and in which our readers could individually engage with little trouble, and with pleasing as well as instructive results: but, in order the better to carry on the inquiry, it is desirable to employ a violin-bow, as, by its means, more vigorous vibration can be excited than by the finger.

25. If, then, we draw a violin-bow across the edge of a goblet, a soda-water glass, or any similar vessel, a musical note is elicited, which depends for its existence, as before stated, on a vibratory action of the glass itself; but in an empty and clean

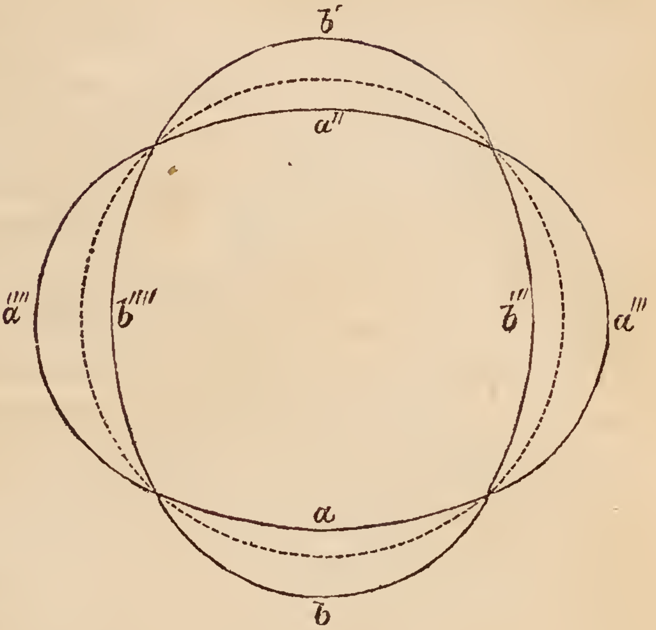


Fig. 1.

glass, we cannot *see* how it vibrates,—whether the whole vessel oscillates to and fro on its leg, as an axis, like a flower or a tree on its stem, or whether the vessel changes its form during vibration. We will proceed to show that the latter is the case, and that the glass, on receiving the first impulse, is thrown into the form a, a'', a''', a'''', fig. 1, which the instant afterwards is changed to the position b', b'', b''', b'''', the dotted circle being the position of the rim of the glass in a state of repose.

26. If we take four little pieces of thin wire, and bend them into the form of hooks, and place them on the edge of the glass, so that one leg of the hook shall be within and the other without the glass,—we shall find that they will be greatly excited during the vibration of the glass, excepting at four points of its edge, at which points the wires will be at rest, or nearly so. These four points are equidistant from each other, and it will be seen that the part where the bow is applied is equidistant between two of them: if the hooks be placed at those points at first, they will remain there; but if at other points, they will travel round to these resting-points. In our figures we necessarily exaggerate the amount of disturbance, in order to show the principle more clearly.

27. The existence of these four points is very pleasingly shown by the use of lycopodium, the seed of the *Lycoperdon bovista*, which possesses a degree of fineness greatly exceeding the generality of powders, each grain being, according to Wollaston, less than the 8500th of an inch in diameter. For the use of this powder, a conical-shaped vessel is better than a goblet; but the latter will do. By sprinkling the lycopodium-dust on the interior surface of the glass (to which a small quantity will adhere), and then vibrating the glass with a bow, a considerable portion of the powder will be shaken from off the surface, with the exception of four narrow lines of powder reaching from the top of the glass a considerable way down: in these lines there is very frequently not only the original portion of dust remaining,

but an additional modicum derived from the other portions of the glass; and it will be always found, that the point to which the bow is applied (which, for convenience, we will call the *point of excitation*,) is midway between two of the lines,—thus preserving the analogy to the hooks and cross-wires. It is, moreover, singularly remarkable, that if the powder be sprinkled on the *outside* instead of the inside of the glass (care being taken to preserve the inside quite free from the powder), a similar thing will occur; viz., four trains of powder will be seen passing down the *inner* surface of the glass: for this experiment a conical glass* must be employed; and with such a shaped vessel it will be found that a little tact will produce this parodoxical effect. It would appear that during vibration, a portion of the powder is carried up by virtue of a certain centrifugal force acquired by the glass, which force is stronger nearer the top than lower down; and that that portion passes over the edge, and settles down into four vertical lines. We will further allude to this mode of explanation presently; but the fact itself is independent of all theory, and is calculated to claim the notice of the experimenter very forcibly, as the transfer is instantaneous.

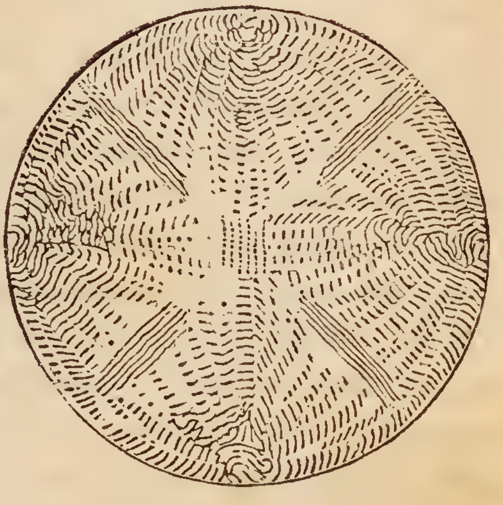
28. To these modes of detecting the existence of vertical lines in the glass, which have different properties from the remainder of the surface, we will now add another, which is, perhaps, more convenient in its application, and more appreciable; we mean, the presence of water, or any other liquid, in the glass. Water, coloured with litmus or ink, to deaden the transparency, will answer very well.

If, when the glass is about half filled with water, it be vibrated by passing the moist finger round its edge, the liquid surface becomes broken up into a figure of four fans, which rotate in the direction and with the velocity of the finger, the latter being always midway between two of the fans,—its pressure causing the point on which it rests at any given instant, to assume the condition of a node; but if the glass be excited to vibration by means of a bow, the surface of the water is thrown into the form represented by fig. 2. From four equidistant points of the glass emanate four fans of liquid undulations, which proceed nearly to the centre of the liquid surface; and it is seen that, whatever part of the glass be chosen as the point of excitation,

* A conical wine-glass will do; and if the glass be blue or green, &c., the effect will be heightened, inasmuch as any figures formed within the glass are more striking from the contrast of a light-coloured powder upon a dark ground.

one of the fans emanates from beneath that point. The oblique action of two contiguous fans raises a faint ridge, which proceeds from each node to the centre; while the extreme ends of the four fans form, in meeting at the centre, a net-like figure, which is generally that of an imperfect square.

Fig. 2.



29. The last corroborative evidence which we shall give, of the existence of these four remarkable points in the circle of the glass, is obtained by the use of any oily or viscid fluid, such as is calculated to adhere to glass more than water does. If the vessel be half filled with such a liquid, (care being taken to preserve the inner surface of the glass, between the oil and the rim, quite dry,) and vibrated by one rather decided stroke of the bow, it will be seen, on viewing the glass horizontally, that four vertical curves are formed by an upward starting or motion of the oil in four places, by which a small stratum is in each case left adhering to the surface of the glass; and, in analogy with previous instances, the point of excitation occupies a position immediately over the highest point of one of these curves.

30. From the above evidence, then, we learn that, during the vibration of the glass, there are four equidistant points round its surface, which produce an effect on any solid or fluid bodies in contact with the glass, different from that produced by the remaining portions of the surface; and, as we have no reason to believe that that property resides inherent in the glass, considered by itself, we have to determine how its manifestation is brought about by the influence of vibration; and to that point we will at once proceed.

31. The first impulse of the bow draws the part of the glass to which it is applied out of its original position, which we will term the *circle of repose:* if, however, that were to occur without a displacement of the other portions of the glass, we should obviously have a circumference of glass, greater than that of the original circle; which could not be. This kind of stretching is, however, opposed by the great compactness of the substance of the glass; and, in order to allow the point of excitation to recede further from the centre, the adjacent sides of the vessel approach nearer to the centre; but, as this inward

impulse proceeds from two points, instead of one, it is double in intensity when compared with the primitive impulse which it was intended to correct: it therefore thrusts out the part opposite to the point of excitation, in order to restore equilibrium. It will now be evident that we have obtained a figure exactly analogous to that of an ellipse: that is, the same quantity of glass is arranged into an oval, of which four points are at their original distances from the centre, two segments at greater distances, and two other segments at less distances, as in fig. 1. The rapidity with which this transformation takes place is such, that we may call it instantaneous: but it is instructive to proceed by steps such as we have attempted, by which we may conceive that, while one segment is thrust outwards, two other segments are drawn inwards, to compensate the disturbance; but, in so doing, produce an effect more than sufficient for the required purpose, and thus produce an opposite disturbance, which requires for its equalization that a fourth segment should be thrust outwards, which fourth segment is diametrically opposite to the segment first excited.

32. If the reader have now succeeded in forming a clear conception of the manner in which the primitive impulse of the bow transforms the figure of the glass from a circle to an ellipse, he will find the subsequent part comparatively easy. When the impulse has produced the greatest displacement of which it is susceptible, a momentary state of rest occurs, in which the glass is elliptical; but its elasticity will not permit a continuance in that form; the compressed portions acquire an outward tendency, and the elongated portions a tendency towards the centre; there must, therefore, be points where these opposite tendencies neutralize each other, and those points must necessarily be the parts of the glass which were not originally disturbed from their position of repose.

33. There is scarcely an instance in physical science of a dynamic impulse losing its effect at the precise point of compensation. A pendulum, moved from the perpendicular, returns thereto by virtue of the force of gravitation; but not only so,—it passes its original boundary, and assumes a position on the other side of the perpendicular. So it is with the four segments of the glass; by the time they have regained their original position, they acquire a momentum which carries them beyond the circle of repose,—the two outer segments passing within, and the two inner segments passing without. A moment's consideration will show that this action must likewise generate an ellipse, of which the longer axis is at right angles to the longer

axis of the former ellipse a, a'', a''', a'''', which it has just superseded: this ellipse we may represent by the letters b, b'', b''', b'''', fig. 1.

34. It will now be well understood that the same causes which produced the destruction of the first ellipse will act with equal force on the second; elasticity will carry the displaced segments back to their original positions, and in so doing will generate a momentum sufficient to carry them beyond that boundary, and thus give rise to the formation of an ellipse similar to the first, and at right angles to the second. Thus these reciprocations go on till the resistance of the air and other circumstances finally, but gradually, subdue them; for it should be understood that each successive ellipse is less elongated than the preceding.

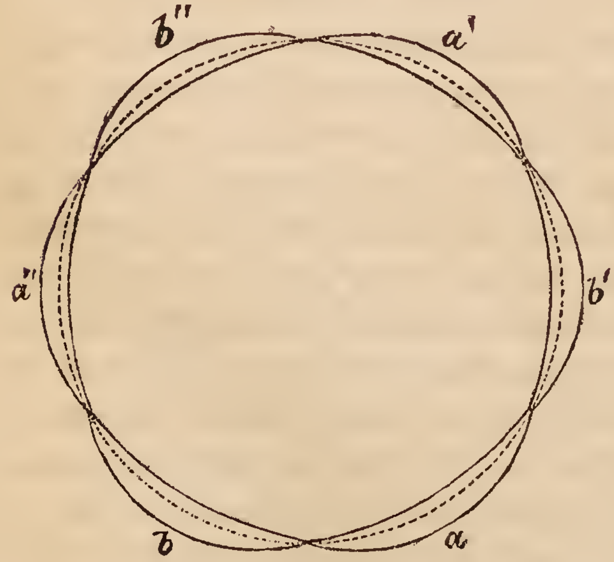
35. The description of these changes necessarily takes a considerable time, but the changes themselves occur with almost inconceivable rapidity, being several hundred times in a second; and as our visual powers are quite inadequate to detect the individual links in such a rapidly recurring series, whatever effect either ellipse considered separately is calculated to produce, we estimate the result as if both ellipses were co-existent; and this will now enable us to explain the quadripartite phenomena before described. If water be contained in the glass, the transformation of the latter from a circular to an oval form necessarily occasions a flow of water from the flatter towards the smaller ends of the ellipse: when the ellipse is reversed, a flow occurs in the opposite direction; and, as the eye cannot detect any interval of rest between the two, an impression of their simultaneous existence is left upon the mind. Thus the form of fig. 2 is presented to us; and thus shall we be enabled to apply the same mode of reasoning to the points of rest indicated by the hooks, water, &c. While the four segments of the glass are rapidly vibrating to and fro, the four intermediate points, being urged both ways, as it were, do not move at all, and any bodies placed against those points will be nearly as quiescent as if the glass were not vibrating: thus, if the little hooks be symmetrically placed equidistant from each other, and the bow be applied midway between two of them, the two consequent ellipses will cut each other at the points on which the hooks are placed, and then those points become nodes or resting-places, which are not likely to disturb the hooks placed upon them; but, if the hooks be placed at other points, or if the bow be applied otherwise than midway between two of them, the hooks partake of the vibratory action of the parts of the edge on which they are rest-

ing, and are gradually shaken to those points where the agitation is less vigorous, and finally attain the nodal points.

36. With respect to the lycopodium-dust, it is evidently shaken from those parts which are actively vibrating, because its adhesion to the glass is very slight; but, as there is no motion occurring at the nodes, there is no reason why it should be removed from thence, and we consequently find that a line of powder remains on the quiescent points. It must here be remarked, that although, for convenience, we have spoken of the glass as a vibrating circle, the effect is obviously carried a considerable depth towards the bottom; so that, instead of nodal *points*, we have nodal *lines*, down which the powder remains undisturbed. Thus may these interesting phenomena be analyzed, and the rationale of their production traced step by step; but the inquiry by no means stops here; we have treated of that combination of circumstances which will induce a system of four vibrating segments in the glass, but we shall find that the same principle, modified in its individual application, is discernible under other conditions, into the consideration of which we will now enter.

37. We have stated that, when the original impulse drew the point of excitation, and an adjacent portion on either side, out of the original position, two lateral segments were impelled nearer to the centre, to institute a balance of forces; but whether those segments shall be at right angles to the original impulse, will depend upon the intensity of the latter. The elasticity of the glass is a constant quantity; therefore, if the force to which it is opposed be variable, the resulting effect will be variable: when, therefore, the bow is drawn *forcibly* across the edge of the glass, the latter is allowed a wider range of displacement before the elasticity produces a compensation, than when the impulse is *less forcible;* and, in order that the segment may recede further from the centre, a larger arc of glass is included within its range.

Fig. 3.



38. If, however, the impulse given by the bow be *less energetic* than that which produced the effects before described, there exist good reasons for believing that the glass

assumes a form analagous to a, a', a'', fig. 3. Let us suppose that the bow is applied, at the point of the glass marked a; a segment is drawn out of the circle as before; but by the time the impulse reaches the nodal points on either side of it, the elastic tension urges the two adjacent portions b, b', within the circle, to restore equilibrium: these three segments together take up a semicircumference, which acts upon the opposite semicircumference by momentum, thus:—the two lateral segments, b, b', by passing too far towards the centre, induce a protuberance in the more remote portions, a', a'', which, in their turn, generate a third depression at b''; thus, then, we obtain three segments exterior, and three interior, to the original circle of repose; which give to the periphery, taken as a whole, the form indicated by a, a', a''. Let us now bear in mind the manner in which, in fig. 1. one ellipse gave rise to another ellipse, which immediately succeeded it, and we shall have but little difficulty in concluding that the same principles will convert the heart-shaped figure, a, a', a'', into a similar figure, b, b', b'', the elongations of the former coinciding radially with the compressions of the latter, and the compressions of the former with the elongations of the latter. There will obviously be in this case, six points, where the two superposed figures will cut each other, and these points, from the principle before alluded to, will be at rest.

This, it will be observed, is a theoretical deduction of what would occur if the primitive impulse were not energetic enough to draw a quarter of the circle out of the position of repose; but we will now proceed to give practical illustration of the existence of these three-sided figures.

39. In drawing the bow across the edge of the glass, it will be found that more than one sound can be heard; frequently four or five; all musical and rich, but all different in pitch. If now, by the presence of water in the glass, we obtain a figure of four undulatory fans on the surface, we shall invariably find that the musical note elicited at that moment is the lowest in point of pitch of all those which it is capable of producing; and as the surface is never broken up into a less number than four vibrating segments, and four nodes between them, it will be convenient to call the musical note produced at that moment, or by that mode of vibration, *the fundamental note.* If now we draw the bow smartly across the edge of the glass with a motion which may be called *quick* rather than *forcible*, we shall obtain the next higher tone, and at that moment the liquid surface will present six vibrating fans of undulæ, equidistant from each

other, and separated by six points, where comparative quiescence is observed.

40. We may now, without any forced analogy, at once refer the formation of this six-sided figure to the superposition of two similar three-sided figures, whose origin we lately discussed. The impulse at the point of excitation is not sufficient to draw a quadrant of the circle out of its original position, its power being limited to an arc of about 60°; two adjoining sextants or sixth parts are by that disturbance thrust inwards; two further remote portions follow the course of the first, and the last sextant is in an opposite state to the first: thus originates the three-sided figure, the duplication of which, produced by all the six segments changing their conditions, conveys the idea of a simultaneous existence of six vibrating segments, as indicated by six fans on the surface of the liquid.

The modes by which the nodes were detected when the elliptical figures were produced, are equally available in the present instance; the hooks, lycopodium, and water, indicate the existence of six points, or vertical lines, as the case may be, in which no vibration is going forward.

41. With a slight modification of the mode of handling the bow, which it is difficult to describe, we can next produce a tone higher in pitch than that which accompanied the six-sided figure; and the invariable result will be a figure of eight sides; that is, eight liquid fans of undulæ will emanate from the sides of the vessel towards the centre of the liquid, and be separated from each other by nodal lines, as before. The reader will not require that we should retrace our steps in detailing the production of this eight-sided figure; a due appreciation of what has been already said will render a brief description sufficient for the present purpose. The impulse communicated by the bow is still less *energetic* than that last spoken of, and only sufficient to influence an arc of 45° of the circle of glass. This arc is generated in a manner exactly analagous to the preceding instances; alternations of excursions and incursions succeed each other all round the glass, eight of such arcs or segments completing the circle, four being without and four within the circle of repose. At this moment the figure approximates roughly to the form of a square, the middle of each side of which is nearer to, and each corner further from, the centre of the glass than when the glass retains its proper circular form. If now the corners and sides of this square become transposed, (which they do through the influence of elasticity,) we obviously obtain an eight-sided figure, the cutting points of the two superposed figures forming

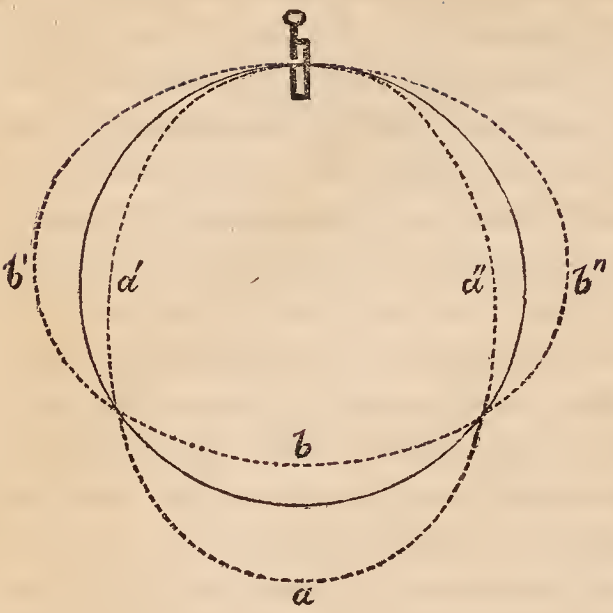
the nodes as before. It must be remembered that, when we say this note is invariably accompanied by a figure of eight sides, we mean that the note is the next higher in pitch to that which produced the six-sided figure; and, in further evidence of the same fact, it will be found that the fourth tone which the glass is susceptible of producing will always be accompanied by a figure of ten sides, whether the indicator employed be water, lycopodium, or wire.

42. Generally speaking, not more than four different tones can be elicited from any one glass: sometimes, however, a fifth is appreciable; but, be the number what it may, the vibrating segments and nodes always increase in number by twos as the elevation of pitch increases, they being 4, 6, 8, &c.

43. A very remarkable and instructive effect is, however, produced, when the edge of the glass is at any one point prevented from vibrating freely: a violin-performer is well aware of the effect resulting from placing a *sourdine* or *damper* on the bridge of his violin,—the tone acquires a peculiar and subdued character, from the circumstance of the vibrations of the bridge upon which the strings rest being interfered with. In like manner, any small instrument which would act as a damper when placed on the edge of a glass, interferes with the production of those effects which naturally result from the free and unshackled vibration of the glass. We have employed a small steel instrument, which clasps the edge by means of a screw; but other modes may be devised, provided that the damper where it clasps the glass presents a certain amount of plane surface, probably not less than a tenth of an inch.

44. When an impediment to free vibration, such as this, is employed, that force of vibration which would otherwise produce a four-sided figure, or one composed of two superposed ellipses, will produce but three vibrating segments, one of which is diametrically opposite to the damper, and the other two so situated as to form with the third, nearly an equilateral triangle, *provided* the bow be applied immediately opposite to the damper; but if it be applied at 45° on either side of that point, four segments will be formed just the same as if no damper were placed on the edge. The rationale is this: the original impulse influences a quadrant (*a*) fig. 4, of the circle, as if no damper were used, and the adjoining segments, *a′ a″*, on either side, are drawn or impelled inwards, in accordance with the elastic tendency; but the third step in the process,—the generation of a fourth segment opposite to the first,—is prevented by the presence of the damper, which will not permit vibrations to

Fig. 4.



occur at the part where it is placed*. The consequence is that the impulse is expended in the production of the two depressions a' a'', without producing the fourth segment opposite to the first. Thus there is only one part of the glass exterior to the circle of repose, while there are two parts within that circle; the consequence of which is, that, when the elasticity has reversed these positions, there result two parts, b' b'', exterior, and one, b, interior to the circle: the rapid superposition of these two figures presents the three excursive segments at apparently the same moment; and thus the triangular form is accounted for. When, however, the bow is so applied as to allow the damper to occupy the place of a node, no interruption is experienced in the vibration, and all four segments are produced.

45. If any of our readers repeat this interesting experiment, it will be seen that the fan a, (fig. 4,) is larger in size than the other two fans, and the splashing of the water will indicate greater activity of vibration at that arc. Now, as the action of the bow elongates the circular rim of the glass into an ellipse, only *one end* of which is beyond the circle of repose, (the damper retaining the other in its place,) its rebounding energy being thus concentrated, as it were, in one vibrating arc, carries it so far towards the damper, that it expends its force by thrusting out of the circle of repose the glass at b' b'' on both sides of the damper, and as near to it as its inertia will permit. There are then, at the second half of each vibration, two portions exterior to the circle of repose; but as b' b'' have to share between them the impetus received from a, that reasonably accounts for the descrepancy between the sizes of the fans at a and b' b''. The efforts, again, of b' b'' to regain the circle of repose, produce their combined effects on a†, which shows the extent of that

* The damper does not act so much (if at all) by its weight, as by its tendency to flatten the curved surfaces of the glass against which it presses, so as to produce that rigidity which is the necessary result of a highly elastic body being permanently held out of equilibrium.

† The excursions of the vibrations at a are sometimes so great as to

combination by being further from the circle of repose than b' or b''; thus do the oscillations continue, and thus does a superposition of two like figures satisfy the conditions of a ter-nodal division, as well as that of an even number of nodes.

46. If we now produce all the other tones of which the glass is susceptible,—retaining at the same time the damper on the edge, and applying the bow immediately opposite to it,—we shall find that the number of ripply fans on the surface of the water is one less than if no damper were present, the numbers being respectively 3, 5, 7, 9, &c. It is not necessary to trace in detail the causes of this; precisely the same mode of reasoning as that just adopted will avail for all; the difference of number being dependant on the difference of *energy* in the first impulse, or, which amounts to the same thing, the extent of curve included in the first segment.

47. All the phenomena which we have been detailing are produced by the violin-bow; but, if the damper be removed and the moistened finger be employed, we perceive four fans of undulæ revolving in the direction, and with the velocity of the finger; the reason of this revolution is, that, as fast as a vibrating segment is produced by the friction of the finger, it is interfered with by another formed by the finger at the succeeding moment a slight distance from it; and thus new segments are continually forming, which give a rotatory appearance to the surface of the liquid. If clean and pure mercury be employed instead of water, the figure upon the metallic surface is very beautiful: if a needle be placed upon the mercury, it will rotate in a direction *opposite* to that in which the finger moves; thus, if the finger employed to vibrate the glass move round its rim in a direction from left to right, the needle will rotate from right to left, and *vice versâ*.

48. With respect to the musical tones elicited from any one glass, it is rarely found that they harmonize with each other; the intervals between them varying from three semitones to an octave. The marked difference observable in this respect is due to a combination of causes: first, the thickness of the glass compared with its diameter; secondly, the perfect or imperfect circularity of its form; thirdly, the amount of equability in the thickness of the glass at every part of the circle. All these circumstances modify the tone produced.

49. It is desirable here to consider a little more minutely

fracture the glass at that part; and it has happened to the writer with a *thin* glass, that the whole sector, *a*, came out, and the remainder of the glass was preserved entire.

the effect of thickness of substance in determining tone. We commenced our inquiry with two questions—"How does a glass vibrate?" and, "Why does a large or thin glass emit a deeper tone than one which is either smaller or thicker?"

The first question we have already answered: a glass, in vibrating, changes its form into an elliptical, or into a three, four, or five-sided figure, according to the tone produced. This figure is succeeded by one similar to, but not coincident with it; and the rapid reciprocation of these two superposed, but not coincident, figures constitutes the vibration of the glass.

The second question finds its answer in the circumstance that the more matter there is congregated in a given space, the larger is the amount of elasticity possessed by it as a whole; and, as a necessary consequence, the more energetically does it resist any disturbing influence from without. When, therefore, we have two glasses equal in diameter, and unequal in thickness, a quadrant of the thicker glass possesses a stronger elastic power than a quadrant of the thinner glass, and by this influence returns, after any disturbance, more rapidly to its position of equilibrium. Supposing, therefore, that the violin bow produce equal displacement in both quadrants, the thicker of the two will rush back to its original position more quickly than the other; and thus the vibrations, which are nothing more than the reiterated attempts of the glass to regain its original place, will be more rapid; and, as elevation of pitch is dependant on rapidity of vibration, the tone elicited from the thicker is more acute than that from the thinner glass.

If the two glasses be equal in thickness but unequal in diameter, the higher tone of the smaller glass is due to the smaller extent of the quadrant of its circle, the thickness being equal throughout. The ratio between the length of the curve and its thickness determines the tone; for the nearer that ratio is to unity, or, in other words, the nearer the two quantities are to equality, the more rapid will be the vibration. In the large glass, therefore, the curve being longer without being thicker, the two dimensions are more unequal than in a small glass; the vibrations are then slower and the tone deeper. If the thickness of two glasses were in the same ratio as the diameters, they would, *cæteris paribus*, emit the same tone. Should the circle be imperfect, or the thickness not be equal in every part of it, discrepancy in vibration must result.

Section III. On the Vibration of certain Vessels chiefly Metallic.

50. In the last section, we attempted to give a familiar explanation of the circumstances which enable a glass goblet to emit by friction a musical sound, and of the modifications of form and structure which give variety to the tones emitted. We now proceed to show that a glass goblet is merely one individual link in a chain, to which we may give almost any length we please; a sure sign that we have obtained not only a fact, or a collection of facts, but a general *principle*, which binds and blends the whole into one system. This is not the place to discuss the subject; but it would be well for students in science to form a just idea of the eminent importance of scientific principles. Principles are to facts what the skill of the architect is to the blocks of stone with which he rears his structures; each individual stone is not fully appreciated until it is combined with its fellows according to the laws of stability, when each one confirms and strengthens the rest. But, to revert to our object, which is to show that a small spark of the soul of music resides in substances, which have hitherto obtained a sad character in the world's estimation for any thing like musical purposes:—such as lead, wood, &c.

51. If metallic vessels were constructed, resembling glass goblets in form, we should be able to elicit musical sounds from them with more or less facility, in the same manner as from goblets; but there are other forms more easy of construction, and of equal, if not superior, efficacy in practice, without any departure from the principle which governs the glass vessel. To pursue this inquiry, we have had constructed a series of shallow vessels, of various substances, and as nearly equal in thickness as circumstances would admit. The form was that of the common Wedgwood-ware evaporating dishes, being shallow hollow vessels, about five inches in diameter, and one inch and a half deep, with a hole drilled through the bottom to receive a screw, which firmly fixes the vessel for the purpose of experiment. In order to enable such of our readers as may have the wish or the facility for verifying these experiments, to adopt the same mode of conducting them, we will describe the kind of apparatus employed.

From a block of wood rises a short wooden cylinder, about two inches high and one inch thick; an internal screw is cut in this cylinder, to which is adapted an external screw with a knob or handle at one end. The vessel which is the subject of ex-

periment is then placed on the top of the cylinder, and the external screw is passed through the hole in the centre of the vessel into the hollow screw cut in the cylinder; and being tightly screwed down, the vessel is in a condition to vibrate freely, as its edge is not interfered with by the screw.

52. This being the general mode of arrangement, we will state the results obtained from vessels of copper, brass, bell-metal, lead, tinned iron, zinc, and wood: but, before we proceed to detail, it is of importance to mention one condition relative to form, which is productive of great modifications in the result. If the vessel be perfectly circular, any effect produced by applying a violin-bow at one point of the edge, would be the same as if it were applied at any other part; but if the vessel have a lip, as in the case of an evaporating dish, the continuity of the circular form is broken, and we are not justified in concluding that the effects would be similar from every part of the edge.

To estimate the amount of difference due to this cause, duplicates of the dishes were made, one with a lip, and the other without; in other respects the dimensions were equal.

53. In order to convey a clear idea of the musical tones, the production of which we shall have to describe, it will be convenient to refer them to some common standard. This standard we will consider to be the middle C of the piano-forte, an instrument which is perhaps more familiarly known than any other. This C is called *tenor* C, by which name we shall hereafter allude to it. All the notes higher than this we shall designate H, and all below it L. The different octaves we will call 1st, 2nd, 3rd, &c., thus;—suppose we have to denote the 2nd B♭ above the middle C of the piano or tenor C, we shall say B♭ 2nd H. Suppose it be the F♯ immediately below the tenor C; we should say F♯ 1st L; and so on. We shall find this abbreviated nomenclature convenient, as it will prevent much circumlocution.

54. Commencing then with the copper dishes, the results, presented by vibration, were as follow:

Copper Dish, not lipped.—Upon half filling this vessel with coloured water and vibrating it by means of a bow in the usual manner, the lowest tone elicited was found to be B 2nd L, and the accompanying phenomenon observed on the surface of the water was a system of four fans, thereby indicating a division of the vessel into four vibrating segments (as explained in the last section). On varying the impulse so as to produce the next higher tone, it was found to be E 1st H, and six fans were formed on the watery surface.

54. In the last section (42) we stated that rarely more than four tones can be elicited from the same glass; but the form, which these metallic vessels presented, rendered them more susceptible of vibration; and in the copper vessel there were no fewer than five tones all higher in pitch than E last mentioned: viz. E♭ 2nd H, B 2nd H, E♭ 3rd H, F 3rd H, B♭ 3rd H; and the number of fans observable on the water were respectively 8, 10, 12, 14, and 16. These invariably even numbers afford a strong confirmation of the mode in which the vessel changes its form during vibration, as stated in the last section; that is, the rapid superposition of two similar figures, which are, severally, figures of an elliptical or of a 3, 4, 5, 6, 7, or 8-sided form. Figures 1 and 3 will sufficiently illustrate the nature of these superpositions.

If we compare the musical notes produced by this one vessel, we shall see that they embrace an extensive range of distance; that is, between four and five octaves; and if we likewise bear in mind the fundamental principle laid down, that the acuteness of the tone depends on the velocity of vibration, we at once arrive at the conclusion, that the segments into which the vessel divides itself are vibrating more rapidly in proportion to the acuteness of tone.

55. Taking, therefore, the middle C of the piano-forte as the result of 256 vibrations in a second, and observing that the lowest tone from our copper vessel is an octave and one note below that C, we arrive at the number of vibrations producing that note by a simple proportion, thus:—as 2 is to $\frac{15}{8}$ (the constant ratio between C and B), so is 128 (half of 256, it being an octave lower,) to the answer required: as $2 : \frac{15}{8} :: 128 : 120$. Thus it appears, that the lowest tone which that vessel is capable of emitting, is the result of a velocity of vibration equal to 120 in a second.

Should the student feel surprised that a copper vessel should change its form 120 times in a second, he must reflect that the power of the mind to conceive rapid motion is bounded by comparatively narrow limits; and he must no more doubt that the fact is so, because he cannot appreciate such a velocity, than that the sun is 800,000 miles in diameter, merely because, to his unassisted eye, it appears so small. One of the results of a healthy tone of mind, is a due appreciation of the power of the senses, whose office of guide to the mind generally, is only exercised with benefit, when under the control of the intellectual faculties in particular, by which its indications are received at all times with respect, and at the same time with

caution, never rudely rejecting, nor eagerly accepting. When the mind of ignorance implicitly adopts the senses as guide, the useful servant becomes the treacherous friend, and the master degenerates into the willing slave.

56. We can now pursue the same system of computation to show the number of vibrations, on which the existence of the other tones depends. Tenor C being due to 256 vibrations, and the second tone from the copper vessel being E, two notes above it, we get another proportion; as $1 : \frac{5}{4} :: 256 : 320$; the first two numbers of this proportion being the ratio between the vibrations producing C and E, as before stated. Tuning Fork (85). We thus obtain 320 as the number corresponding to E, and following the same track, we obtain the remaining numbers, which come out thus:—

E ♭=608, B=960, E ♭=1216, F=1365, B ♭=1814.

We may, perhaps, observe, that for the production of the three flat notes, we have taken a mean between the two notes above and below. If we now remember the number of nodal divisions into which the vessel was thrown, as indicated by the rippling undulations on the surface of the water, we obtain the results represented by the following table:—

Order of Succession.		Pitch of Note.	No. of Nodal Divisions.	No. of Vibrations per Second.	Angular Dimensions of each Vibrating Arc.
1st	Fundamental note, or most simple in character.	B 2nd L	4	120	90°
2nd	Secondary tones.	E 1st H	6	320	60
3rd		E ♭ 2nd H	8	608	45
4th		B 2nd H	10	960	36
5th		E ♭ 3rd H	12	1216	30
6th		F 3rd H	14	1365	25 43′
7th		B ♭ 3rd H	16	1814	22 30′

A careful perusal of this table, and a consideration of the manner in which the elements of it have been obtained (with especial regard to the ratio existing between the vibrations producing the seven notes of the musical scale), will give the reader a considerable insight into the fundamental principles of Acoustics. The laws which govern that beautiful science may be divided into two classes,—one relating to the production of vibratory action, and the other to the conduction and propagation of those vibrations through the air; the latter we have no need here to refer to, but the former will be brought familiarly under the

reader's notice, by referring to the phenomena presented by the copper vessel.

57. These experiments were followed up by another series, in which the copper vessel, similar in other respects, had a lip protruding at one side. In this case a difference of tone was distinguished, not only as being due to a difference in the number of nodal divisions, but also to the determination of the circumstance whether or not the lip formed part of a vibrating segment: when the bow was applied at the lip, the latter became the centre of a vibrating segment, and there were several other points, which, if chosen as the points of excitation, would place the lip in a vibrating segment; but there were also many points that would place the lip in the condition of a node, or a quiescent part bounded by two vibrating segments. Now, it was found that, when the point of excitation was so chosen as to throw the lip into a vibrating segment, the tone was lower, generally by about a semitone, than when the lip assumed the condition and property of a node. We must here be understood as implying that the force of excitation was the same in both cases, and the number of liquid fans of undulæ also the same.

58. It is not difficult to trace the source of this difference; the lip being unsymmetrical in shape, and interfering with the general contour of the vessel, the equability of vibration is broken, and the lip, on account of its spreading form, which gives it the effect of a larger segment, vibrates more slowly, and emits a tone more grave in pitch; but when the lip is placed in the condition of a node, its disturbing effect is lessened, and the tone elicited from the vessel is nearly the same as if the latter were perfectly circular. It will likewise be easily conceived that the more the lip is thrown out of the general circle of the vessel, the greater will be the discrepancy. Under any such circumstances as these, the vibrating power of the vessel is lessened, and the number of tones capable of being elicited from it is subject to the curious conditions which we have just explained.

59. In order to compare the phenomena presented by this vessel with those detailed respecting the vessel without a lip, we will subjoin a similar table, in which the effects of the lip are estimated by the difference of tone and difference of velocity in the vibrations producing them. The reader will understand that, when the lower tone of any given nodal division is mentioned, it is implied that the bow is applied at the lip; but that, when the higher tone is alluded to, the bow is so applied as to throw the lip into the condition of a node.

Order of Succession.		Pitch of Note.	No. of Nodal Divisions.	Angular Dimensions of each Vibrating Arc.	No. of Vibrations per Second.
1st	Fundamental tone.	B, B♭ — 2nd L	4	The form of the lip rendered this indefinite.	120, 114
2nd	Secondary tones.	E, E♭ — 1st H	6		320, 307
3rd		E♭, D — 2nd H	8		608, 576
4th		B, B♭ — 2nd H	10		960, 907
5th		F, E♭ — 3rd H	12		1365, 1216
6th		B♭, A♭ — 3rd H	14		1814, 1622

Here, then, we see the nature of the influence which any interruption to the continuity of the circular form exerts. We shall have to make a few remarks on other similar obstructions; but we wish at present to pursue the details respecting the metallic vessels.

60. The two hitherto described were of *Copper;* but the next experimented on were of *Brass:* in these the facility of vibration was not equal to that in the copper, considered with reference to the number of tones produced; there being only five in the brass vessel without a lip, and only three doubled tones in the lipped vessel. By *doubled* tones we mean the two depending on the same number of nodal divisions; but the range embraced by those five tones was remarkably extensive, the lowest being E 1st L, and the highest being A 5th H,—an interval of nearly $5\frac{1}{2}$ octaves, the lowest being due to 160, and the highest to 3413 vibrations in a second of time. No musical instrument (used as such) can give any idea of the piercing acuteness of this upper tone: it is elicited (as, indeed, are all the tones emitted by these vessels) by a peculiar handling of the bow, which gives a sudden but not a violent impulse to that portion of the rim of the vessel on which the bow is placed. The lipped brass vessel presented a similar feature to that of the copper vessel: viz., a deepening of the tone when the bow was applied at the lip; the extent of this depression of pitch was about a semitone, but not musically accurate in that interval.

61. Two dishes formed of *Bell-metal* were then made the subject of experiment: in that which had not a lip, the highest tone was the same as in the brass vessel; but the lowest was

not so low in tone by an octave as the lowest in the brass vessel, the interval between the different tones not being so wide: the notes produced were F, B ♭, A, F, A, the first four of which were in different octaves. An eye accustomed to musical symbols will instantly see that there is no harmonious relation between the different notes, if sounded together; and the same remark applies in the former instances with even still greater force.

62. The employment of *Tinned iron* vessels was productive of very favourable results, as they admitted of being made very thin, without injuring the elastic character of the metal. From the tinned iron vessel without a lip, seven tones were elicited, which, if they could have been heard at one time, would have been even more discordant than those before alluded to: they embraced a range of about 4½ octaves, the lowest, B 1st L, and the highest, F ♯ 4th H; the former being due to 120, and the latter to 2902 vibrations in a second.

63. The lipped vessel of the same material presented results very similar to those previously described, there being, however, five doubled tones, whereas the brass emitted but three. It might not, perhaps, be expected that *Zinc* would be particularly calculated for these experiments; it will be seen, however, that it is not behind the more sonorous metals (as they are generally considered), when vibrated in the manner which we have adopted. The whole series of tones was higher in pitch than in any of the former vessels; the lowest, or fundamental, tone being E 1st H, while the highest was A 5th H: the tones produced were seven in number, discordant as before, (when considered harmonically,) and accompanied by a breaking up of the liquid surface into 4, 6, 8, 10, 12, 14, and 16 vibrating segments respectively.

64. *Lead*, from the difficulty of forming it into vessels of great thinness, and from its generally inelastic character, is a very unfit source of sonorous vibration; two vessels, however, formed of that metal, yielded two tones each, one due to quadrinodal, and the other to sex-nodal division: the interval between the tones was 1½ octaves, the notes being G and C in adjacent octaves. A vessel formed of the same material, and provided with a lip, yielded the same two tones when the lip was chosen as the point of excitation; but each was lowered a semitone when the lip was made to assume the position of a node.

65. The next pair of vessels was of *Wood*, being formed of hard beech, turned to a considerable degree of thinness.

From these vessels, that without a lip yielded three tones, viz., B ♭ 1st L, F 1st H, F 2nd H, the result respectively of 240, 341, and 682 vibrations in a second. The lipped beech vessel emitted F 1st L, and C ♯ 1st L, with 4 vibrating segments: G ♯ 1st H and G 1st H with 6 segments: and G 2nd H, and F ♯ 2nd H with 8 segments.

With respect to these vessels of wood, the wonder is, not that the notes were limited to three in number, but that so many as three could be produced, considering the material of which they were made. The unlipped vessel furnished an interesting example of the effect produced by a want of homogeneity in the structure or texture of a vibrating body. The vessel had been slightly cracked, but the fissure was repaired with glue: the effect of the glue, however, gave a rigidity to that part of the vessel, and when the part happened to be a centre of vibration (or midway between two nodes), the resulting note was a quarter of a tone *deeper* than when the same part was in the condition of a node. The explanation is at once easy and instructive: when the defective part was at a nodal line, its rigidity was of no moment, as it took no part in the vibration; but when it became a centre of vibration, it slackened the velocity by its greater stiffness and imperfect elasticity. It was curious also to observe, in many of these instances, that any inequality in the thickness of the material of which the vessel was formed always produced a slight depression of the tone, when the thickened part became a centre of vibration: the remark which applied to the glued fissure in the wooden vessel will avail to explain the cause of this depression of tone.

66. The vessels which we have now described were all made to the same dimensions, in order to bring them more prominently into comparison with each other. Subsequently, however, a similar train of experiments was instituted on the vibration of a larger vessel, nine inches in diameter, and made of zinc; and the result will show how greatly the power of producing these tones is increased by employing larger vessels. It is obvious, from a comparison of the results obtained from this vessel with those elicited from the smaller vessels before described, that we can place no limit to the extent to which these tones can be produced by increasing the size of the vessel, provided that the circularity of form, homogeneity of structure, and equability of thickness, be attended to as much as possible.

We will give a tabular view of the results obtained from this vessel, as the nature and extent of the increased facility with a larger vessel will be better appreciated by instituting a compa-

rison between the results from it and the particulars enumerated in the two preceding tables.

Order of Succession.	Pitch of Note.	No. of Nodal Divisions.	Angular Dimensions of each Vibrating Arc.	No. of Vibrations per Second.
1st Fundamental notes.	F, E 1st L	4	90°	171, 160
2nd Secondary tones.	B, A ♯ 1st L	6	60	240, 226
3rd	A 1st H	8	45	427
4th	C ♯ 2nd H	10	36	544
5th	E, D ♯ 2nd H	12	30	640, 608
6th	A, G ♯ 2nd H	14	25 43′	853, 810
7th	C ♯ 3rd H	16	22 30′	1088
8th	G, F 3rd H	18	20	1536, 1365
9th	B ♭ 3rd H	20	18	1814

It must be observed that this vessel was provided with a lip, and the doubled tones given above were determined by the nodal or segmental position of the lip. A few vacancies will be seen in the filling up of the table; this arose from the great difficulty of eliciting any given tone with sufficient continuance to estimate both the pitch of the tone and the number of liquid fans on the surface of the water; so that those only have been included in the table whose value was duly appreciable. From the experiments now described, we obtain an idea of the modifications which a lip produces on the tones elicited from a vessel of a form in other respects circular; but we may trace the existence of a similar principle, when the circle is broken by any obstacle which retards the vibration at any given point.

67. If we take a common drinking-mug or cup with a handle, and vibrate it by means of a bow (observing at the same time that no part of the sides of the vessel is touched by the hand), we shall find that, when the bow is applied at such a point as to place the handle in the centre of a vibrating segment, the tone heard at that moment is a semitone lower in pitch than when the handle assumes the character of a node: this may even be detected by resting the vessel on the hand, and passing the finger round the edge. If we listen for a sound analogous to that emitted from a glass goblet under such circumstances, we shall certainly fail; but by applying the ear close to the vessel, we shall detect an exceedingly faint and soft

sound, which we may, perhaps, without incorrectness, call a *musical whisper;* and it will likewise be found that when the finger is passing close to the handle, or at 90° or 180° from that point, the sound will be considerably lower than at the four intermediate positions. That the existence of the handle is the cause of this depression of tone is sufficiently shown by cutting off the handle (which may be done by means of a small saw moistened with turpentine); and when the amputation is neatly and cleanly performed, the vibrating power of the vessel is not at all injured, and the tones elicited from it are the same in pitch, whatever part of the edge be chosen as the point of excitation.

There are some earthenware and glass vessels, in which the outer surface is fluted, or reeded, or both; and whenever such a state of things occurs, the depth of the tone is sure to be influenced by the determination of the circumstance whether, or not, the reeded or thickened part be in active vibration.

68. If any circular body be taken, such as a common plate or a disk of glass or metal, and if this be mounted, and held firmly in the centre, a certain number of tones is producible from the plate or disk, at whatever part of its edge the bow be applied; but this number of tones can always be doubled, by screwing to the edge a damper, as mentioned in the former section; the damper acting the part of the lip and handle in the vessels, whose vibrating action we have just considered. If disks be used, and it be desired to employ a liquid upon them, this is easily effected by melting some bees' wax, and running it round, a little within the circumference; in this way a disk is converted into a very shallow vessel.

69. In all the experiments which we have detailed, in which metallic vessels were made the subject of inquiry, they were filled to about half their height with water; this necessarily deepened the tones elicited from them; for, at every vibration, each segment of the circle has to move not only itself, but a bulk of water resting against it: thus the velocity of vibration is diminished, and the tone resulting lowered in pitch. It is, therefore, probable that, if no water were present in these vessels, a greater number of tones might be elicited than those which we have mentioned; but the desire to ascertain clearly the number of segments into which the circle was divided in each instance, led to the employment of water, as this indicated the nature of the impulse to which the glass was subjected with undeviating accuracy.

70. It may here be observed, that the fans on the surface

of the water, extend the less towards the centre of the liquid surface, in proportion to their number: this obviously follows from the circumstance that, as the number of vibrating segments increases, the dimensions of each and the extent of its vibratory excursions diminish, and the water which presses against it receives a smaller impulse.

71. We have now stated the principal results obtained from this series of experiments; and have endeavoured throughout to trace the production of the observed phenomena to causes which are, in most cases, adequate to their explanation. Before quitting the subject, however, we wish to subjoin a few details on the effect of the application of heat to sonorous bodies.

All the vessels which were used in these experiments, were at the ordinary temperature of the atmosphere: several of them were, however, afterwards raised to 200° or 300°, in order to ascertain whether any change of *tone* resulted from the change of temperature; but it did not appear that such was the case, the only change being that the tones assumed a *cracked*, imperfect character, by no means equal to that elicited at ordinary temperatures.

72. How far heat, as a general principle, influences musical tones, is not yet well understood; but there is an experiment not popularly known, which places in a prominent point of view, the agency of heat in producing sound.

Mr. Trevellian, a few years since, accidentally discovered, that when heated metal is placed upon cold metal, in such a manner that a *rocking* can easily be produced, the ready passage of caloric from the heated to the cold metal will engender a tremulous motion of the former, and so rapid that a very perfect and beautiful musical note is produced. One method of performing this experiment is as follows: an oblong plate of copper, about half an inch thick, convex on one side, and having a rod or handle projecting from the centre of one of the short edges, is heated to between 300° and 400°, and then placed across a ring of cold lead, about six inches in diameter: the heat immediately darts from the heated copper to the cold lead, and with such a degree of momentum, that the copper plate, being convex on its under surface, and resting on a notch cut in the ring of lead, rapidly rocks to and fro, as a watch-glass would do, if laid on a table, with its convex side downwards, and touched with the finger.

73. We have endeavoured to ascertain how far there might be any analogy between the metallic vessel and the heated copper plate, and have found that, when the plate was vibrating, besides the principal tone produced, which bore some resemblance

to the tone of an organ, and was very rich and perfect in character, there was always another tone to be heard, of a higher pitch; this upper tone, however, was not always harmonically related to the fundamental note; for instance, in one experiment the tone elicited was G 1st L, and a faint B a tenth above it was also heard at the same time; in a few minutes, when the temperatures of the two metals had become less dissimilar, the fundamental tone suddenly changed to E flat; while the secondary tone became likewise E flat. In another experiment, the interval between the two tones was a fifth, which suddenly changed to a seventh, when the heat had partially equalised itself: thus showing that, although a secondary tone could always be distinguished, it bore no constant relation to the fundamental tone. It should be observed that the metals are placed over a hole made in the cover of a thin wooden box, which acts as a sounding-board, and by its resonance, greatly invigorates the tone.

74. It thus appears from the results detailed, that in the goblet, in the metallic and wooden vessels, and in the copper plate, the secondary tones bear every sort of musical relation to the proper or fundamental tone; and that however gratifying to the mind it may be, to generalize facts, and seek for analogies between different phenomena, we must be carefully on our guard to avoid *forcing* a coincidence or resemblance between different classes of phenomena; such, for instance, as those which we have been considering in this paper, and those connected with the vibration of a stretched cord, which we referred to in the TUNING-FORK. In the latter case, during the production of any given tone by the application of a violin-bow, two or three harmonic tones can be heard, such, in fact, as we have called *secondary tones;* but with this especial difference, that in the string, the secondary tones are the 5th, the octave, and the 12th, above the fundamental tone, and are, therefore, in perfect harmony with it; hence the term *harmonic;* but in the instances of these circular vessels, the relation between the different tones presents every sort of interval, concordant and discordant. This must caution us against straining an analogy further than it will apply. Physical facts are to principles what scions and buds in the process of grafting and budding are to stocks—if the scion or bud of one species be grafted upon the stock of another species, between which Nature owns a relationship, however distant, the result will be beneficial; but if we endeavour to assimilate different families, to force an affinity which Nature refuses to sanction, the result will show that we have made a bad use of good materials.

75. Here we conclude our article on the Harmonica; and if some of our readers should think that copper dishes and musical glasses have not much connexion with each other, we would urge upon their consideration, the fact that the difference between them is only apparent. The beautiful tones of the Harmonica naturally lead an inquiring mind to seek how such tones are produced; and when we find from accumulated evidence that the circular rim of the glass is divided into separate vibrating segments, during the production of the tones, it is but natural that we should inquire whether vessels made of other substances will exhibit symptoms of a similar action, when placed under similar circumstances. Thus have arisen the three sections of this paper; and we conclude with a hope that we have succeeded in eliciting some scientific knowledge by means of a fiddle-bow, a drinking-glass, and a metallic dish.

IX.

THE PRISM.

Even Light itself, which every thing displays,
Shone undiscover'd, till his brighter mind
Untwisted all the shining robe of day;
And from the whitening undistinguish'd blaze,
Collecting every ray into his kind,
To the charm'd eye educ'd the gorgeous train
Of Parent colours. First the flaming red
Sprung vivid forth; the tawny orange next;
And next delicious yellow; by whose side
Fell the kind beams of all-refreshing green.
Then the pure blue, that swells autumnal skies,
Ethereal play'd; and then of sadder hue
Emerg'd the deepen'd indigo, as when
The heavy-skirted evening droops with frost.
While the last gleamings of refracted light
Died in the fainting violet away.—THOMSON.

From a Poem to the memory of Sir Isaac Newton.

1. IT was a sublime idea of one of the ancient philosophers, that, if the Almighty were to become visible to mankind, he would choose Truth for his body, and Light for his shadow. Indeed, there are few subjects upon which the Natural Philosopher lingers with more instruction and admiration, than upon the laws which regulate the various and splendid phenomena of Optical science. The theories of the production and propagation of light, have long engaged the master-minds of first-rate mathematicians, to whom it presents subjects worthy of the most refined analytical skill. To trace the progress of a ray of light through its various reflexions and refractions, (whether as concerns the exquisite mechanism of the human eye, or that admirable specimen of human ingenuity, the reflecting telescope of the astronomer,) is productive of most valuable results. To decompose such ray, and estimate the varieties of colour so produced; to extend the information thus acquired, to the infinitt variety of Nature's beauteous aspect, from the plainest flower to the rainbow's splendid arch:—all this forms but a small part of the study of that wonderful fluid (if such we may call it) which, when God created, he pronounced "good."

2. When in the full possession and enjoyment of so great a blessing as light, it is often difficult for us to estimate correctly all its advantages. Experience would tell us, that deprivation alone makes us sensible of the value of a recent possession. Man, in his restless progress through life, is continually struggling to gain a position beyond the one he actually occupies; a prospective advantage, which his fond and ardent fancy presents to him, not only as desirable, but as almost capable of ensuring perfect felicity. A being of warm hopes and high aspirations, he is not content with a stationary position. He struggles to improve it, and often barters certain good for imaginary felicity. What wonder, then, if he sometimes exchange his pure gold for dross covered over with glittering tinsel, whose worthlessness actual possession and use can only detect.

As, by contrasting his present inferior position with the happiness of that which he may have lost, a man learns to value above all price the good which he may no longer call his own, so may we learn to value the gifts with which we are blessed, if we can, for a moment, so far put aside our instinctive selfishness, as to place ourselves in the situation of one whose means of communication with the external world are fearfully limited:—of one deprived of sight. By contemplating such an one, and transferring his deprivation to ourselves, we can, perhaps, learn to value the possession of a sense, with which, if suddenly deprived of it, we should think the very desirableness of our existence is united. Great, indeed, must be the loss, when so mighty a mind as that of our immortal Milton, so rich in stores within itself,—

A genius universal as his theme;
Astonishing as chaos, as the bloom
Of blowing Eden fair, as heaven sublime:

when such a mind, which we should think scarcely depended upon external objects for support, pours out its plaint in language as remarkable for its fervid and convincing tone of truth, as for its poetical aspiration, we are enabled to form a somewhat correct idea of the value of light, and of the organ by which it is appreciated.

——— Thus with the year
Seasons return; but not to me returns
Day, or the sweet approach of even or morn,
Or sight of vernal bloom, or summer's rose,
Or flocks, or herds, or human face divine;
But cloud instead, and ever-during dark
Surrounds me, from the cheerful ways of men

> Cut off; and for the book of knowledge fair,
> Presented with a universal blank
> Of Nature's works to me expunged and rased,
> And wisdom at one entrance quite shut out.
>
> *Paradise Lost*, B. 3.

3. The subject of the *Prism* is connected with one of the most interesting epochs of Optical science. To the sagacity of our own Newton is due the proof, that a beam of pure white light is composed of several coloured rays, each of which possesses different properties from all the others. In considering this subject it will be desirable, *First*, to point out some of the most important and general properties of light; and *Secondly*, to connect the *Prism* with that part of Optics called *Chromatics*, or the doctrine of *Colours*.

Section I. On Light.

4. Light forms one of the series of bodies or agencies, of which we know nothing except by the effects which they produce. The limit to the power of human intelligence is perhaps in no way more instructively shown, than by the barrier which often prevents us from connecting effects with their most intimate causes. The effects of Heat, of Light, of Electricity, of Odour, &c., are familiar to us, and have furnished the inquiring minds of philosophers with constant materials for the exercise of their powers :—but the nature of any one of those agencies is still unknown :—whether it be a subtle fluid, or a state of vibration, is a question to which science has directed, and must still continue to direct, all her high energies. We will not, therefore, commence our details with any theoretical exposition of the nature of light, but we will analyse some of its effects, concerning which, perception is less likely to err.

5. Let us suppose, then, that we are placed in view of a lighted candle, or in such a position that the candle can, popularly speaking, *shine* upon the eye: let us next suppose, that a common looking-glass is placed on one side of the room; and a convex and a concave mirror on another side of the room; both mirrors being in such positions that we can, as it is familiarly expressed, *see the candle in them;* in the third place we will suppose that there are interposed, in succession, between the candle and the eye, a square of glass, such as a window-pane, and a globe filled with water, such as is used for the abode of gold and silver fishes. The reader is probably aware of the effects produced on the appearance of the flame of the candle, by the bodies we have named; but we propose to examine these effects minutely, in order to deduce certain general principles

from them, which may be applied to a large variety of phenomena of more or less familiar occurrence. This inquiry will be more satisfactorily carried on, if we consider the different cases separately, in the following order:—

i. The direct effect of the candle.
ii. The effect of the looking-glass.
iii. The effect of a convex and of a concave mirror.
iv. The effect of an interposed square of glass.
v. The effect of an interposed globe of water.

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6. i. *The direct effect of the candle.* When we steadily regard a lighted candle, we are conscious, whether the face be turned directly towards the flame or not, that the eye, at least, is turned in that direction. If we direct our attention a little on one side of the flame, we obtain a faint and indistinct view of it; but if the obliquity be much increased, the image of the flame is entirely lost.

Now, if a person look at the eye of another, when the latter is regarding the flame of a candle, he will find that, so long as the latter person obtains any view of the flame, a straight line may be drawn from the flame to the pupil of the eye, uninterrupted by any opaque object, such as the nose or other parts of the face; but as soon as it is found, and even before, that a straight line cannot be so drawn from the candle to the pupil, it is also found that the individual cannot see the candle. Now, if we roll up a piece of paper into the form of a hollow tube, the flame of the candle can be seen through it, only when the axis of this tube coincides with the straight line drawn from the pupil of the eye to the candle. If the tube be bent, the flame cannot be seen through it. These experiments justify us in the conclusion, that the flame of the candle dispenses its light in straight lines; for, if such light had the property of bending, or following a curved line, there is surely no reason why it should not bend so as to enter the eye which is turned away from it; or to fall upon the eye, which is looking into a bent tube directed towards it. We may likewise infer, that, when the light enters the eye in a direction perpendicular to the pupil, that is, when the candle is immediately opposite the eye, the view of the candle is more distinct than when it is placed obliquely with reference to the observer.

7. Under such circumstances as we have just described, we are impressed with the idea that the sensation experienced through the medium of the eye, is derived from the candle itself; and such is the conclusion which all the inquiries of the

philosopher tend to confirm. We may, therefore, state, in general terms, that so long as the eye sees the candle by direct vision, something emanates from the flame, or some process takes place by which the eye is affected with the sensation of light. This substance or process, producing such a sensation, is called a *ray of light.* Now, as we do not wish to involve ourselves in any particular hypothesis, we say that *rays of light* pass from the candle to the eye, and there induce the sensation of vision; without expressing any opinion as to the material, or the vibratory character, of such rays.

8. We may now inquire whether the size of the rays, or the velocity of their motion, can be determined. With respect to the former question, we may state, that the size of the rays, if known at all, is so inconceivably small, that it is useless to institute a comparison of them with any familiar object, without confusing the reader more than instructing him. We know that, if we interpose a sheet of paper between the candle and the eye, and make a minute hole in the paper, the light will penetrate to the eye; provided the hole be in the right line joining the candle and the eye:—nay, the very translucency of the paper itself proves that some of the luminous rays must pass, or at least communicate their effect, through the minute pores or openings in the fibres of the paper; because the light, which appears to be shed over its surface, can come from no other source: we shall find it convenient therefore, at least for the present, to consider each ray of light, when separated from surrounding rays, to be immeasurably small.

9. The velocity with which the rays pass from the candle to the eye, we cannot test by means of the candle itself. If we ignite it, the emitted light appears to reach the eye at the same moment, and we are not conscious that any portion of time, however minute, elapses between the two occurrences: we must therefore recur to other tests. Suppose that two persons are situated, one on each of two hills which are two or three miles asunder, and that the two persons have chronometers whose indications are precisely alike; and that it is agreed that one of them should fire a cannon at a preconcerted moment. The other also will see the flash at the same instant of time that the match is applied;—that is, however accurate the construction of the chronometers may be, and if they coincide precisely in their indications, yet, the flash of the cannon discharged at a particular moment, as marked by one chronometer, will be seen by the person on the opposite hill at the very same moment as marked by the other chronometer. Hence, it would appear that

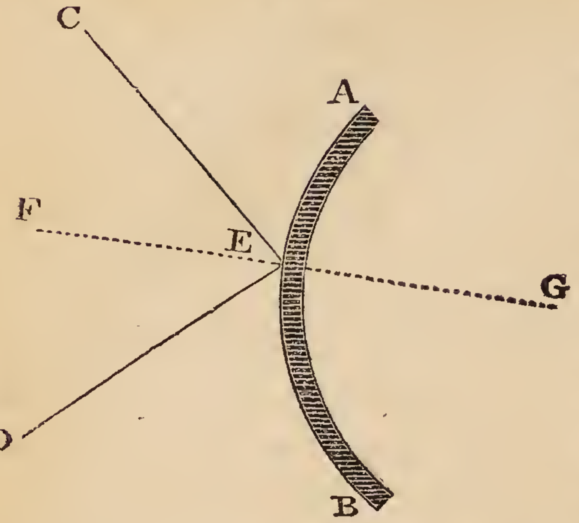
few for consideration. The ray, C *a*, having impinged on the surface at A, is reflected in the direction, *a a'*, which makes an angle with the glass equal to the angle made by the line of incidence C *a*. Now, as the eye, E, is not situated at that point, it cannot receive that reflected ray, and has, therefore, nothing to do with it. As the approach of the ray, C *b*, to the glass is more oblique than that of the preceding ray, so is its reflected ray more oblique, which takes a path, *b b*, forming with the glass the same angle as was formed by the incident ray; but still it does not approach the place occupied by the eye, E. The ray, C *c*, exceeds in obliquity both of the former, and consequently its reflected ray, *c c'*, exceeds in obliquity the former reflected rays. It is now found, however, that the reflected ray, instead of passing in front of the eye, goes beyond it, and is therefore invisible as in the former cases, owing to an excess in the opposite direction; which excess is further increased with respect to the ray, C *d*, which throws its reflexion in the direction, *d d'*. But we shall find one particular point, R, so situated, that a ray, C R, will, after reflexion, take such a path, R E, as will carry it precisely to the pupil of the eye, E, and produce nearly the same effect, as if the candle itself were at the point, R.

16. It thus appears that there is only one spot on the looking-glass, from which the reflexion of the rays of the candle will reach a stationary eye; and we see that this is a consequence of the law, that "the angles of incidence and reflexion are always equal." As we shall frequently have to refer to this law, we will abbreviate its enunciation by calling it *the law of equal angles*. If now we inquire what becomes of the innumerable rays, which impinge on the glass, but which do not reach the eye after reflexion, we shall find that they fall on the ceiling and walls of the room, and on other objects situated around, and that they thus heighten the brilliancy which such objects present to the eye; because, as we shall hereafter see, it is by light reflected from opaque objects that we become acquainted with their presence, and their optical properties. These being the results when a *plane* mirror, or looking-glass, and a lighted candle are made the subjects of experiment, we are now prepared to examine the phenomena presented by a *convex* or a *concave* mirror, occupying the place of the plane mirror.

17. iii. *The effects of convex and concave mirrors.* We are now to suppose that, instead of the plane reflecting surface, we have the *convex** mirror, A B, (fig. 3,) with the candle at C,

* A *convex* mirror may be made by taking a plaster impression of the concave surface of a watch-glass :—fill the glass with mercury; and with

Fig. 3.



and the eye of the observer at D. The rays of light proceeding from the candle, as from the centre of a sphere, cover the surface of the mirror with a brilliant sheet of light, of which we shall select a few rays to illustrate the effects. A ray from C to the upper part of the mirror at A, is reflected from the surface at A, in a direction which forms an angle with the surface of the mirror at that point, equal to the angle of approach. The equality of angles is more difficult to ascertain on a spherical, than on a plane surface; but, if we suppose a disk, such as a crown-piece, or a piece of card-board, to be placed on the mirror at the point, A, so as to present a flat surface, the effect of the reflexion at the point, A, will be the same as if the surface were flat at that point. One ray falls on the mirror perpendicular to the surface, and by a curious application of the same law returns by the same path to the point C. The reason is, that the angle of its approach is reckoned by the number of degrees of deviation which the incident ray makes with a perpendicular to the surface of the glass at that point:—the perpendicular ray therefore has 0° for its angle of incidence, and therefore 0° for its angle of reflexion; or, in other words, the reflected ray takes the path of the incident ray, but in a contrary direction.

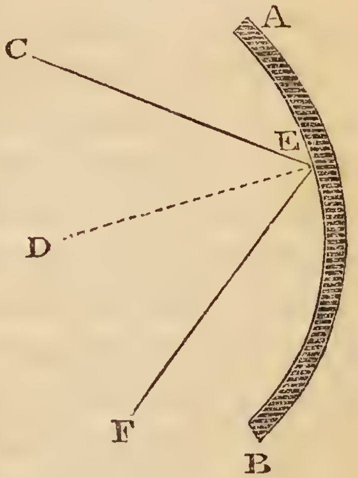
Rays falling on other parts of the mirror, are reflected into various paths by the operation of the same law. We thus see that none of these rays can enter the eye after reflexion; but

a piece of tin-foil spread evenly over the convex surface of the mould, and secured at the edges, which may lap over a little so as to be somewhat larger than the glass, invert the mould into the glass. The glass may be set in the mould used in making a concave mirror; or, if it do not fit it, make another mould of the convex surface of the glass, to serve as a support. The mould covered with tin-foil, having been placed on the mercury with a gentle pressure and a circular kind of motion, force it down upon the glass, and squeeze out the mercury; then keep up the pressure for some time by a weight, as in the case of the plane mirror. The concave mould, being here merely a support, must be removed first. Having cut off the extraneous tin-foil, and removed the other mould, a *convex mirror* will be produced.

there is another ray, or small bundle of rays, C E, which will, after reflexion, follow the path, E D, and enter an eye, at D. If we confine our attention to these rays, we shall find that the effects produced, are the same as would result from a mirror with as many plane surfaces as there are rays, the middle points of which would be the points of incidence; but, as we know that the number of rays falling on the mirror is incalculably great, so must the size of each of these little imaginary plane surfaces be incalculably small.

18. Such of our readers as have viewed the reflexion of their own faces from a convex mirror, must have remarked the diminution in the size of the image when compared with that from a plane mirror. The explanation of this circumstance is important; but we shall find it convenient to trace the progress of reflexions from a *concave* mirror, before we inquire into the cause of the change of dimensions in the reflected image.

Fig. 4.

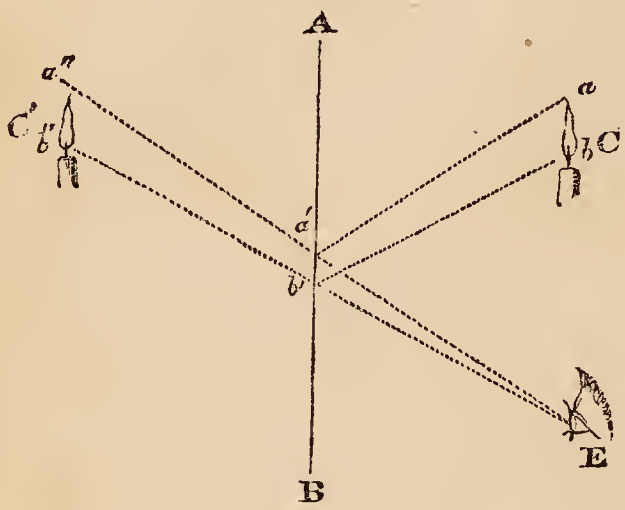


19. Let A B, (fig. 4,) be a *concave* mirror; that is, a mirror whose reflecting surface is on the concave side. If various rays of light fall on the surface from the candle at C, they will, as before, be reflected in various directions. There will, however, be this general distinction between the reflexion from this mirror and those from the former: that the reflexions, scattered widely apart from one another by the convex mirror, are congregated near one another by the concave mirror. The eye being situated at F, there is, as before, only one ray, C E, which will, after reflexion, enter the eye at F. In the case of the concave mirror, as in the two former instances, only a small portion of the surface appears illuminated, as seen by the eye; that portion is, however, comparatively larger on the concave reflector than on the others; and this circumstance brings us to the consideration of the variations in the size of a reflected image.

20. What we mean by the *size* of an object, is the apparent distance between its extremities, or the space included by its outline. If, therefore, we say that the image of an object, (the flame of a candle, for instance,) appears larger in one reflecting surface than in another, we mean that the edges and extreme points of the flame appear to be further asunder in one image than in the other. To trace, therefore, this cause of difference in size, it will be convenient to consider the progress

of *two* rays from the candle, one from each side of the flame, and to study the law by which those two rays retain or vary their distance from each other.

Fig. 5.

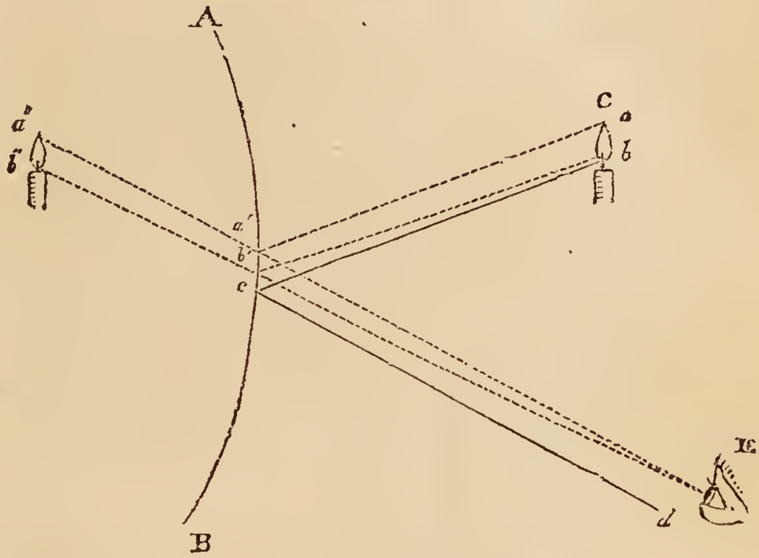


Let *a a'*, (fig. 5,) be a ray proceeding from the top of the flame, and *b b'*, another ray from its base. Now, if we carefully note the angle, *a a'* A, we shall find that E *a'* B is equal to it; and that the angle, *b b'* A, is equal to the angle, E *b' b*. It will, moreover, be found, that the distance between the two points, *a' b'*, is smaller than between the two points, *a b*, of the flame. In fact, the diminution of size is exactly the same as if A B were a *transparent* glass, and the candle were placed at C', at as great a distance behind A B as C is in front of it. As a line appears to be only half its former length, if removed to double its former distance, we may infer, that if the distance of C' behind the glass, be equal to the distance of the eye, E, in front of the glass, the two points, *a' b'*, on the glass are exactly half as far asunder as the two points, *a'' b''* at C'; because C' is twice as far from the eye, as is the glass. But we have seen, that the dimensions of *a' b'* on the transparent glass, are just the same as from a reflecting surface, the flame in the former case being as far behind the glass, as it is in the latter case in front of it. From all this we conclude, that, if the flame, C, and the eye, E, be at equal distances in front of the reflecting surface, the apparent height of the reflected image will be exactly half the height of the flame itself, placed at the position *a' b'* : or, with reference to its area or surface, instead of height, it would be one fourth of the size. If the relative distance of the flame and the object be varied, the proportion in the size of the image would vary also.

21. Suppose that we exchange the plane for the *convex* mirror. We shall now find that the distance, *a' b'*, (fig. 6,) is much smaller than in the former instance; and, as our notion of the size of the image is derived from the distance between *a'* and *b'*, we decide immediately that the image in the convex mirror is smaller than in the plane mirror. The reason why the two points approach nearer together in the convex reflector, is, that

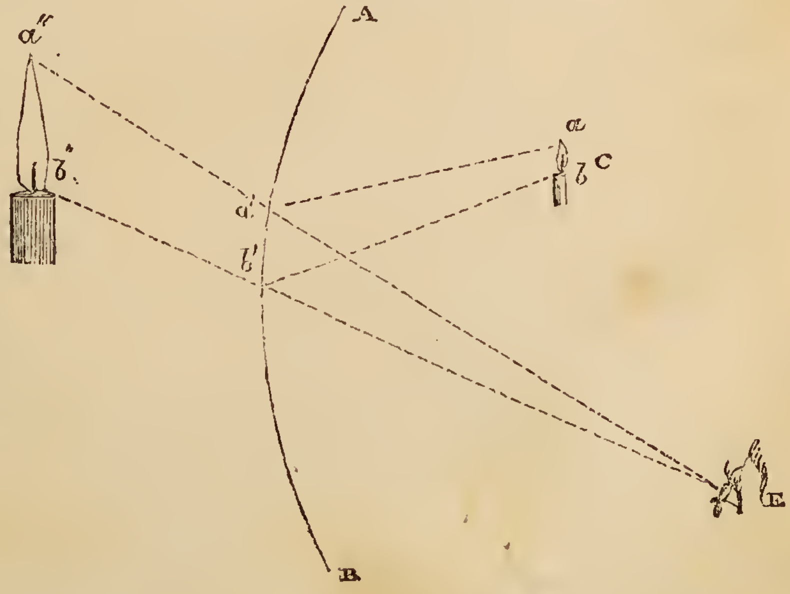
the law of equal angles is rigorously maintained, whether the reflector be plane, convex, or concave. Let us take a ray from the lower part of the flame, which ray shall be represented by an unbroken line *b c*, such, that the interval on the mirror shall be half the size of the flame:—we shall find that the lower ray would, on account of the curvature of the glass, be reflected in the direction c *d*, and not enter the eye; but when we diminish the interval between the points *a′* and c, we arrive at that particular distance which will convey the reflected rays of the top and of the bottom of the flame into the eye: that distance or interval being always smaller in a convex reflector than in one which is plane. Thus, the law of equal angles is the sole source of the variation of size in reflected images.

Fig. 6.



22. Let us now employ a *concave** instead of a convex mirror, and we shall find that the two rays, one from the top and the other from the base of the object, which enter the eye, are farther asunder as *a′ b′*, (fig. 7), at the surface of the mirror, than in either of the former instances; and thus present to the eye a larger image. If, in this case, as in the others, we trace the operation of the law of equal

Fig. 7.



* A *concave* mirror may be formed from a watch-glass by first taking an impression, in plaster of Paris, of the convex surface of the glass. When

angles, we shall find it to be quite adequate to account for the production of this increase of apparent dimensions. If, instead of the two rays which we here consider, we take two at any other distance from each other, we shall find that one or both would not enter the eye.

By continuing the lines, which carry the reflexion to the eye, to the other side of the mirror, we see in every case, the reason why the image appears as to size equal to, greater, or less than, the object. Thus, in the *plane* mirror, the virtual or supposed image $a'' \ b''$ is of the *same size* as the object $a \ b$; in the *convex* mirror, the virtual image $a'' \ b''$, is *smaller* than the object $a \ b$; and in the *concave* mirror, the virtual image $a'' \ b''$ is *larger* than the object $a \ b$. Thus arises the perception of difference of size.

23. We arrive then at the conclusion, that, in order to account for the enlargement or contraction of dimensions in a a reflected image, we have only to follow out the law of the equal angles; and that, this law being constant, the varying form of the reflecting surface determines the change of dimensions. The very remarkable effects produced, when the flame or other luminous object is placed at certain distances with respect to the centre of curvature of the mirrors, will occupy our attention in the article on the *Telescope*.

24. Suppose that, instead of a convex or a concave mirror, we have a polished metal urn, or a piece of polished silver plate: we find that the flame of the candle is reflected from each of them; but distorted in form, and variable in dimensions. This arises from the circumstance, that the curvatures of the surfaces of such articles are seldom symmetrical; but be the form what it may, the whole of the reflected appearances of the flame may, by careful examination, be traced to the operation of the law of equal angles. It is a very beautiful instance of the universal operation of a law of Nature,—and it shows at the same time, the importance and value of what we term a *principle*,—that the

the plaster mould is dry, cut out a piece of tin-foil of the exact size of the convex surface of the glass, and fit it into the mould. Rub this over with mercury as before, and then pour as much mercury into the concave mould as will nearly fill it. Place the convex surface of the glass upon the mercury; and depress the glass gently, but forcibly, and with a circular motion, so as to exclude all the air. Most of the mercury will escape at the edges in making concave and convex mirrors; so that the moulds should be placed in a plate, or other vessel, which may receive the fluid that runs over. When the glass is fully depressed, and all the air excluded, set a weight upon it, and leave it, as before. Upon removing the mould, the amalgam will adhere to the glass, and a *concave mirror* will be made.

multiform reflexions which meet our eye, some from plane reflectors, some from convex or concave mirrors, and others from surfaces variously curved, are all dependant, for the form and dimensions which they exhibit, on the operation of the simple law, that "the angle of reflexion is always equal to the angle of incidence."

25. iv. *The effect of an interposed square of glass.* We now arrive at that part of our inquiry which relates to the act of *looking through* a transparent body at the lighted candle, instead of looking at the reflexion of its light from a polished surface.

If we place a clean piece of glass between the eye and the candle, we can see the latter with nearly as much distinctness as if the glass were not present. To effect this, it is obvious that the rays of light must permeate the glass, as they permeated the particles of air in former examples; because it would violate the laws previously announced, that the light which we see should pass round the glass.

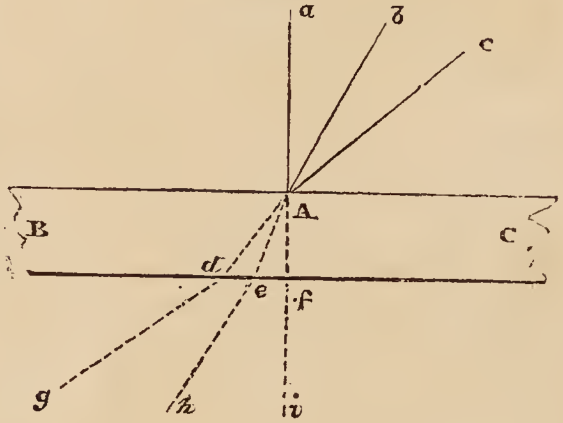
26. But, although the light passes with nearly its original brilliancy through the glass, yet, in most cases, the flame assumes a distorted, wavy appearance. When, however, we employ a square of plate glass, the distortion of the figure of the flame does not appear: the light seems to the eye nearly as brilliant, and the form of the flame as perfect and symmetrical, as if the glass were not present. Now, if we endeavour to discover by inspection whence comes this apparent difference to the flame by using plate-glass, or common window-glass, we shall find that the surface of the former appears perfectly flat, and even throughout its whole extent, and that it is of equal thickness; while the surface of the latter is uneven and covered with indentations and irregularities more or less marked.

27. We may, therefore, naturally suppose, that the derangement of the form of the object, when viewed through common glass, is mainly owing to the irregularities in the surface of the glass. But how? If the light pass uninterruptedly through the glass, why should any irregularities on its surface modify the appearance of the object seen through it? This we must now explain:—It is true that the light passes through the glass in such quantity, as to occasion but little diminution of its brilliancy; but it does not pass through in precisely the same right line in which it approached its surface. We must here, therefore, slightly modify our proposition, that "light passes in right lines," by appending to it the condition, that the medium or space, through which it is moving, shall remain the same in density and other properties. When the ray of light encounters a

new medium, it becomes *refracted*, or *bent*, out of the path which it was previously following, and is constrained to follow a new path; but when this new path is once entered upon, the ray perseveres in the direction of a right line, from which it does not deviate until a third medium, different from the second, is presented to it. Let us now inquire in what direction this *refraction*, or *bending*, is brought about; and to do so more satisfactorily, we will suppose that we have a piece of thick plate-glass, whose surfaces are perfectly parallel with each other.

28. Let us then suppose B C, fig. 8, to be a piece of plate-glass, of great thickness from A to *f*, to show the principle more clearly. If a ray of light, *a* A, impinge perpendicularly upon the surface of the glass, it will pass through it without deviating at all from its original direction: that is, *a* A *f i*, is a right line. This, however, is the only ray whose direction remains unchanged. A ray *b* A, impinging in an oblique direction, will be bent towards the perpendicular line; that is, in the direction A *e*. On emerging from the opposite surface it is again bent, but in such a manner that its subsequent path is in the direction that it had, before entering the glass; or, in other words, the ray or path *e h*, is parallel with the ray *b* A.

Fig. 8.

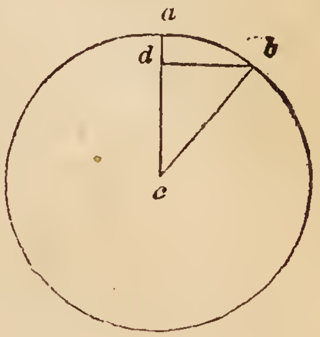


If we now observe a third ray, *c* A, whose direction is still more oblique, we find that it likewise is bent towards the perpendicular, and that that bending is greater in amount than was noticed with respect to the ray *b* A: the new path is A *d*, which, emerging from the second surface, is changed into the direction *d g*, which is parallel with the original ray *c* A. The means by which we determine that the refraction of this third ray is greater than that of the second ray, is, that the angle *b* A *c*, is greater than the angle *e* A *d;* if those angles were equal, then the bending of the two rays would be equal:—but this cannot occur in any piece of glass.

29. This variation in the amount of refraction is not of a vague and fitful character; it depends upon a law as regular as the law of equal angles in the case of reflected light. To expound this law, we shall not be able to dispense altogether with the language of mathematics; but we will endeavour to render the details as simple as possible. If, in fig. 9, we draw two

lines $c\ a$, $c\ b$, from the centre of a circle to the circumference, and at the point d of one of these lines, draw a perpendicular to meet the end b, of the other line; then we call $c\ b$, the radius; the opening between the two lines is the angle $a\ c\ b$; the line $c\ d$ is the cosine, and $d\ b$ is the sine of the angle $a\ c\ b$. The radius, the sine, and the cosine, therefore, form a right-angled triangle, of which the point of contact between the sine and cosine is always the right angle. This is a constant rule for all angles within a quadrant of a circle.

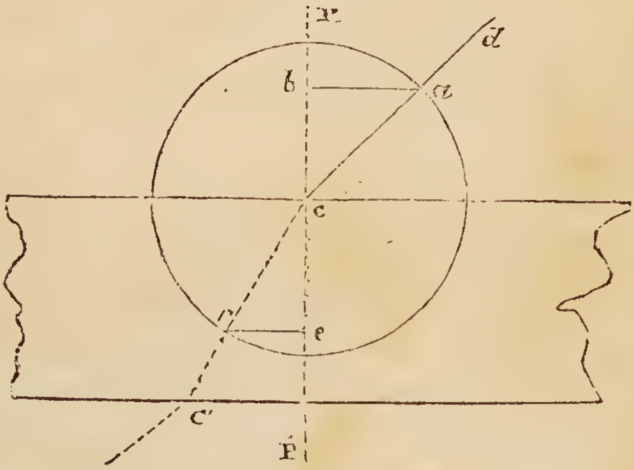
Fig. 9.



30. We are now prepared to examine the following statement;—that *the sine of the angle of incidence and the sine of the angle of refraction bear a constant ratio to each other in any one substance.*

31. Let us recur to the piece of plate-glass. Tables, computed for the purpose, have assigned for the ratio between the sines, for glass, about $1\frac{1}{2}$ to 1: there are many different degrees, but we will assume this ratio on account of its simplicity. We will now suppose that a ray $d\ c$, (fig. 10), impinges on the glass obliquely at c. To determine the sine of the angle of its obliquity, we describe a circle round the point c; draw the perpendicular P P′, passing through the glass, and a line at right angles to that perpendicular, from such a point b, as to meet the point a, at which the circle intersects the incident ray. We see that the angle $b\ c\ a$, or P $c\ d$, is the angle of incidence, and that the line $b\ a$ is the sine of that angle. We must now follow the direction of the refracted ray through the substance of the glass, and institute the following proportion:—*As* $1\frac{1}{2}$ *is to* 1, *so is the sine of the angle of incidence, to the sine of the angle of refraction.* Suppose in our figure, the sine of the angle of incidence $b\ a$, to be $\frac{3}{4}$ of an inch:—then, as $1\frac{1}{2} : 1 :: \frac{3}{4} : \frac{1}{2}$; by which we find that the sine of the angle of refraction must be half an inch in length. We therefore measure off half an inch in a direction perpendicular to the line P P′, but on the opposite side of that line. This half-inch line

Fig. 10.



must be taken at such a point *e*, that the other end of it shall just meet some one point of the circle, which we find to be the point *f*, and a line is then drawn from C to *f*. Knowing, therefore, that the angle P C *a*, is the angle of incidence, and that *b a* is its sine, we may now conclude that the angle P′ *c f*, is the angle of refraction, and that *e f* is its sine; and thus we perceive that we have obtained the required position of the refracted ray, or that the ratio between the sines is as $1\frac{1}{2}$ to 1. If the sine of the angle of incidence be aught else than $\frac{3}{4}$ of an inch, the sine of the angle of refraction must vary in the same ratio.

32. We stated that, when one ray impinges more obliquely than another ray, the refraction is greater. Thus it was found to be, when measured simply by the angles; but when considered with respect to the *sines* of those angles, it is found that the ratio of the lengths of those sines remains constant in the same substance. If, therefore, in our figure, we were to insert a large number of rays, we should find that the ratio between the sines of incidence and refraction for each given ray would be constant. We do not give other rays, because they would detract from the simplicity of the figure; but we recommend to the student, as an instructive exercise, to trace for himself the progress of refracted rays, on a larger scale, first obtaining the ratio of the sines, which for glass, is $1\frac{1}{2}$ to 1.

It is necessary that the reader should in this, as in many other scientific computations, duly appreciate the distinction between a *ratio* and a *difference*. If we were to say that the sine of the angle of incidence exceeds the sine of the angle of refraction by a constant quantity, we should pronounce a falsehood; because that would imply that, if we subtract the smaller quantity from the larger, the difference would be constant. But, when we speak of a *ratio*, we mean that, if one quantity be divided by the other, the quotient will be a constant quantity. Thus, if we divide 20 by 12, and then 30 by 18, we get in both cases $1\frac{2}{3}$ or $\frac{5}{3}$, for the quotient; but if we subtract 12 from 20, and then 18 from 30, we get for the *difference*, in the one case 8, and in the other case 12. It is, therefore, in the sense of a *ratio* that we compare the sines of incidence and refraction.

33. It may now be asked, "What is the law of the refraction, when the ray of light passes from the second surface of the glass into the air; and why the ray now assumes a direction parallel with that which it had before it entered the glass?" To answer this, we find that parallelism is attained in a ratio, which may be considered as the reciprocal of that before employed; the substance of the glass remaining the same throughout:—as 1 is to

$1\frac{1}{2}$, so is the sine of the angle of incidence to the sine of the angle of refraction. In this case the ray, *c f*, (fig. 10,) is considered as the incident ray, and the point *c'* the centre of the circle with which we are to determine the sines of the angles. The process is similar to that before detailed, with the exception, that the sine of the angle of incidence is considered as 1, and that of the angle of refraction $1\frac{1}{2}$. When the two terms of the ratio change places in this manner, the ratio is called the *reciprocal* of the former. All this is connected with the law that, "when a ray passes from a rare into a denser medium, the angle of incidence is greater than the angle of refraction;" and that "when a ray passes from a dense into a rarer medium, the angle of refraction is greater than the angle of incidence."

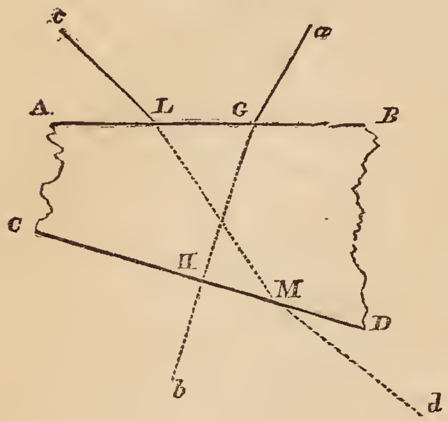
34. But this ratio between the sines, although constant in any one substance, is different in different substances. In some it is greater, and in others less, than in glass. In order, therefore, to obtain a convenient language by which to compare the different ratios of the sines, one term of the ratio is always omitted, which is considered to be unity, or 1; while the other, which is put into the decimal form, is alone used, and is called the *index of refraction.* Thus, the index of refraction of the glass of which we have been treating, is 1·5. In this way extensive tables of the indices of refraction of different transparent bodies, have been arranged; from which tables we select a few substances, in order to show the great variation in this property in various bodies.

	Index of Refraction.		Index of Refraction.
Diamond . . .	2·439	Crown-glass, from 1·525 to	1·534
Phosphorus . .	2·224	Castor-oil . . .	1·490
Glass, 3 parts lead, and 1 part flint . .	2·028	Oil of Olives . .	1·470
Glass, 2 parts lead and 1 part flint . .	1·830	Alum	1·457
Ruby	1·779	Alcohol . . .	1·372
Sapphire . . .	1·794	Water . . .	1·336
Quartz . . .	1·548	Ice	1·309
Amber . . .	1·547	Air (atmospheric)	1·000294
Plate-glass, from 1·514 to	1·542	Oxygen . .	1·000272
		Hydrogen . .	1·000138
		Vacuum . .	1·000000

35. So far we have gained information respecting the refraction, or bending, which a ray of light experiences on entering the surface of a plate of glass; but we are not yet able to explain the cause of the wrinkled appearance of objects seen through common or crown-glass. Before we can do this, we must consider what would occur if the two surfaces of our piece of plate-glass were not parallel. We have seen that, if the surfaces be

parallel, the ray which emerges from the glass, will be parallel with the ray which was incident on its first surface: but we must now enquire how a deviation from parallelism in the surfaces of the glass influences the parallelism of the rays.

Fig. 11.



36. Suppose that our piece of plate-glass is ground into the form represented by fig. 11, in which the two surfaces A B and C D are not parallel; and that a ray of light *a* G impinges on the upper surface; then the law of the sines will bend it towards its perpendicular, in the direction G H; but on emerging from that surface it cannot again assume a direction parallel to the original path, on account of the obliquity of the two surfaces; but it emerges in a direction H *b*, nearly perpendicular to the lower surface of the glass. But, suppose that the ray impinges on the first surface in the direction C L; it will be bent into the direction L M: and on emerging from the second surface it will be again refracted into the path M *d*. It is thus seen that one ray deviates from parallelism towards the perpendicular, and that another deviates towards the second surface of the glass, according to the direction of the incident ray with respect to the lower inclined surface C D.

37. We thus arrive at the important result, that, if the two surfaces of the glass be not rigorously parallel, the rays of light are permanently turned from their original direction. If the difference of thickness, at different parts of the glass, be greater than is represented in our figure, the deviation from parallelism of the incident and emergent rays will be still greater.

38. Let us now apply this reasoning to the distorted appearance of objects, viewed through the wrinkled window-glass. The manner in which a sheet or table of crown-glass is made, renders it impossible that equality of thickness can be ensured throughout. The molten glass is worked out by a whirling motion, into a flattened, thin sheet, which varies in thickness at different parts, however carefully it may be made. Suppose, now, that we look at the face of a person through a piece of such kind of glass. It may happen that the portion of glass, which is in a line with the eye of the observer and of the observed, is tolerably flat, and equable in thickness: but it may also happen that the part of the glass, which is in a line with the eye of the observer and the mouth of the other person, is somewhat curved

in form and unequal in thickness. In this case the mouth will appear crooked, too large, or too small, &c., according to the nature and extent of the defect in the glass; while the eye will appear in its proper place, and of its proper form, because the glass at that point has its two surfaces parallel.

This is strikingly shown when a piece of fluted glass, such as is sometimes used for shop-windows, is employed. Here, if the flutings be very deep, all definite outlines of objects, viewed through the glass, are lost; but, if the grooves be but slightly depressed, we see the forms of objects, viewed through the glass, strangely and often grotesquely changed. If we look through the sides of a cut-glass goblet, we find that the form of a candle, or other object, is not much changed, when a plain or even portion of the glass is opposite the eye; but, when a part, ornamentally cut, is between the candle and the eye, the form of the flame undergoes a great change, on account of the varying thickness of the glass. It may happen that the upper part of the flame may be refracted downwards, and its base upwards or on one side; which must necessarily occasion much distortion.

39. Here, then, we arrive at some definite information as to what results when a transparent body, such as a square of glass, is interposed between the flame of a candle and the eye. If the two surfaces of the transparent body be perfectly parallel, then will the rays of light, which emanate from the candle, and penetrate the first surface, leave the second surface without suffering any change of direction with respect to one another. But, even in this case of perfect parallelism, the path of emersion is not in the *same* right line as the path of incidence: it is *parallel*, but *not continuous* with it. When, however, the two surfaces of the transparent medium are not parallel, we have seen that a decided change of direction takes place; which change is more extensive, as the deviation from parallelism of the two surfaces increases.

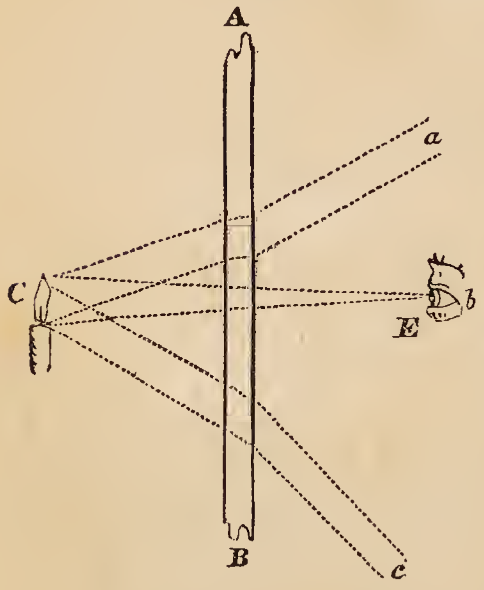
40. It is important to remember, also, that the amount of this change of direction is not uncertain or empirical, but depends upon a fixed law, which may be separated into three parts:—1. The sine of the angle of incidence bears a constant ratio to the sine of the angle of refraction in any substance; 2. If the ray pass from a rare into a denser medium, or, in other words, if the index of refraction of the second medium be greater than that of the first, the ray is bent nearer to the perpendicular; 3. If the ray pass from a dense into a rarer medium, the ray is bent farther from the perpendicular. These two latter conditions are expressed arithmetically, by placing, in the *first* case, the refractive index for the sine of incidence, and unity, or 1, of the sine of

refraction; and, in the *latter* case, by taking unity for the sine of incidence, and the refractive index for the sine of refraction.

41. v. *The effects of a Globe of Water.* The reader has probably seen globular vessels of water, such as those intended for the reception of gold and silver fishes, and has noticed the peculiar appearance of a light viewed through such bodies. These effects, apart from colour, may be observed in the large globular vessels which frequently fill up the shop-windows of apothecaries. We will now endeavour to determine the mode in which such bodies alter the form of the flame of a candle, or of any other object viewed through them.

42. If we look at the table of refractive indices, we see that water bends from its original direction a ray of light, which impinges on its surface. As water and glass, therefore, both possess the refractive property (although it appears to be stronger in the latter substance than in the former) we will suppose that we have a globe of solid glass, and will endeavour to trace the progress of a ray of light through it. Before doing this, however, it will be convenient to show that, however large a square of flat glass may be, when interposed between a lighted candle and the eye, the eye only catches that bundle of rays from the candle, which passes through one particular point of the glass.

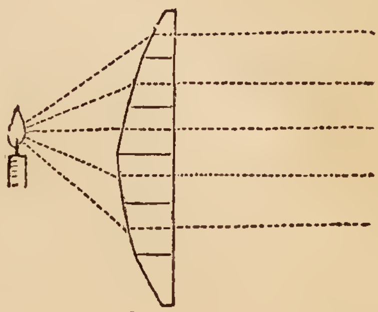
Fig. 12.



Thus if A B, fig. 12, be a section of the glass, C the candle, and E the eye of the observer: of all the rays emanating from C, of which C *a*, C *b*, C *c*, are three, only one ray can enter the eye at E, which ray passes in a right line from the object through the glass to the eye. If, therefore, a number of observers could place their eyes at different points *a*, *b*, *c*, &c., behind the glass, each eye would obtain a view of the candle, by means of a ray, not available for any other position. If we now replace the glass plate with a glass globe, equal in diameter to the length of the glass plate, fewer eyes would obtain a view of the candle; but each eye would obtain a more brilliant view, by receiving two or more clusters of rays instead of one. In order, therefore, to arrive at this truth by easier steps, we will suppose that three or four pieces of glass, of unequal thickness, are placed edge to edge, in such a way as to present on one side a gradually receding surface, as in fig. 13.

If we now trace the progress of several rays, proceeding from the candle, we find that, by virtue of the constant law of refraction, they bend, after immersion, into directions much more parallel with one another than in the instance of an uniformly flat surface. In the present instance, we have represented them as being parallel with each other; but it depends conjointly on the distance of the candle from the glasses and on the obliquity of the surfaces of these pieces of glass, whether the emergent rays shall be quite parallel.

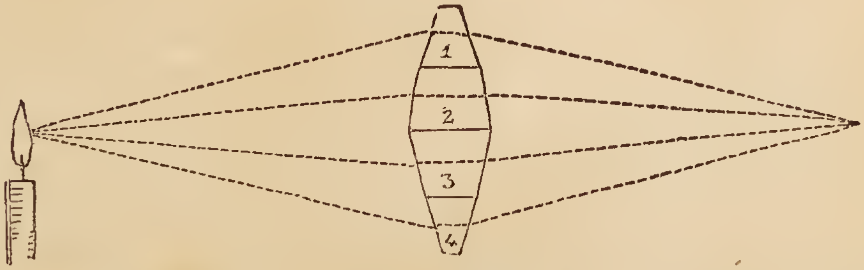
Fig. 13.



43. If this effect be produced by such varying obliquities on one surface of the combined glasses, we may naturally infer that an increased effect will result from the existence of similar obliquities on the other surface.

Let us then suppose that we have several layers of glass, placed face to face, the extreme edges presenting surfaces of varying obliquity. The rays proceeding from the candle impinge on the front surface of the combined glasses, and we assume that the obliquity of the central anterior surfaces 2 and 3, fig. 14,

Fig. 14.



is such as to refract the two rays which enter those surfaces into directions parallel with each other. The outer layers 1 and 4 have their nearer and farther extremities so much more oblique, that they counteract the obliquity of the exterior rays C 1, C 4, and bring them likewise into parallel directions. Now, as the law of refraction is maintained with respect to both surfaces, modified by *direction*, we may expect that, as the four rays emanated *from* a point at first, they will converge *to* a point after emerging from the second surface, under the condition that the second surface is a counterpart of the first.

44. The reader will now understand that such a degree of obliquity may be chosen for each of the glasses composing this assemblage, as will produce the parallelism of the rays here spoken of: and when we remember that the degree of refraction

increases with the obliquity of the incidence, we cannot doubt that such an arrangement of surface may be adopted. But, instead of supposing that three or four pieces of glass are placed side by side, or edge to edge, we may suppose that the same number of faces may be ground upon a solid mass of glass, with precisely the same optical effect. We may likewise reasonably infer that the number of sides or faces need not be limited to three or four, but that they may be increased to ten, twenty, one hundred, or to the greatest number to which the ingenuity of the artificer could attain; and that, by a judicious arrangement of obliquities, as many rays might be brought to parallelism in the substance of the glass as there were faces on its anterior surface. Nay, more;—we may imagine the multiplication of faces to go on to infinity, although not actually producible; until, at last, we should arrive at such a degree of minuteness for each face, that the whole surface would assume the appearance and possess the properties of a curved surface: so that every ray impinging thereon would have a different obliquity of approach from that of the next adjoining ray.

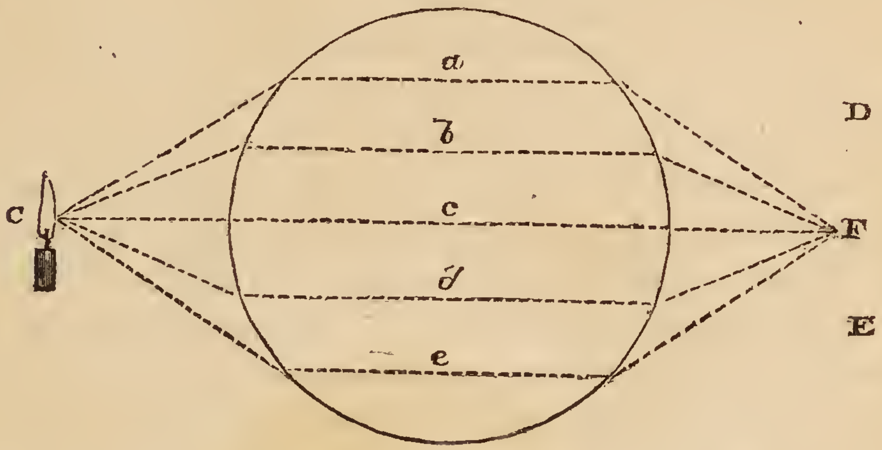
45. We thus arrive, by steps, at a figure similar to that of the globe of glass or of water, which we had previously assumed; and we now see reason for believing that, if the surface be that of a perfect sphere, the candle may be placed at such a distance from it that all the rays, which fall on its nearest surface, will traverse the substance of the sphere in directions parallel with each other; and that, by the influence of the same law, those rays will, after emerging from the sphere, converge again to a point, which it is likewise easy to perceive will be as far from the posterior surface of the sphere, as the point of divergence (the candle) was from the anterior surface. This is actually found to be the case, both by experiment and mathematical computation: whatever material may form the substance of a transparent globe, there is a certain distance, constant for that material, at which, if a candle be placed, its rays will be so refracted as to pass through the surface of the globe in parallel directions; and then to converge to a point, at an equal distance on the other side. It is proper to remark, however, that there are a few rays (those most removed from the centre) which do not quite attain a parallel direction. There is a mathematical reason for this deviation, which assumes the name of *spherical aberration;* and may be entirely removed by slightly altering the curvature of the surface. This deviation is, however, of no moment in our present inquiry.

46. The distance of the point of divergence, at which the

candle must be placed in order to produce these effects, is different in different substances, according to the index of refraction; but we may assume for glass a distance about equal to the radius of the sphere. It may be somewhat more or less than this according to circumstances; but this value is a convenient mean.

Let us then take a globe of glass, fig. 15, one inch and a half in diameter, and place a candle C at a distance of three-fourths

Fig. 15.



of an inch from the surface of the sphere: then rays C *a*, C *b*, C *c*, C *d*, C *e*, from the candle, after impinging upon its surface, will be refracted into parallel directions, as shown in the figure; and after emerging from the posterior surface, will converge again to a focus F three-fourths of an inch distant from that surface.

If the eye be placed near the focal point F, a bright glare of light will enter the eye, and an appearance of great refulgence will be presented: whether the attention be directed towards the upper, the lower, or the central part of the globe, there is a light, proceeding from the candle, presented to the eye. But we have only considered a few of the rays out of the vast assemblage which emanates from the candle; and when we recollect that all, or nearly all, of the innumerable rays of this assemblage, possess like properties, we perceive how it is that the whole surface of the glass globe presents a mass of refulgent light to the eye which is at the focus F.

47. It may now be asked whether this additional supply of light is obtained without depriving other parts of their proper share. We shall see that such a deprivation is really endured in other directions; for, if two other observers place each an eye at the points D and E, they receive no light at all from the candle, because the rays which they would have received,—had the

interposed body been a *plate* of glass,—are turned from their course and directed to the focal point F, when the interposed body is a *sphere*. Thus it appears, that the focal point F can obtain an additional supply of light, only by depriving other points of their wonted supply.

48. We are now in a condition to consider the globe of water, and the large bottles of the apothecaries. In these cases, the refracting body is fluid instead of solid; but, with the exception of variation in refractive power, there is no difference between solids and fluids, as refracting bodies. When we stand at a few yards' distance in front of an apothecary's window, and observe the intense green, and red, and yellow light, which passes through the globular vessels filled with liquids, we may satisfactorily refer the production of the increased intensity of light, to the causes explained above. There is generally a bright gas-flame placed immediately behind those vessels; and although no attempt is made to adjust the distance, so that the refracted rays shall pass parallel through the globe of liquid, yet the rays are of necessity brought nearer to parallelism than before impact; and being thus brought nearer to the central ray (that which passes from the flame through the centre of the globe) congregate, and produce upon the eye of the observer, placed in the focal axis, a greatly increased impression. If we now go a little on one side of the central line, as it might be from F to D or E in our *last* figure, we shall find that the light of the gas-flame is nearly or quite hidden from us: the fact is, that the light, which we should otherwise have received in that direction, has been drawn out of it, and bent nearer to the central ray.

49. The like explanation will serve for the globe of water in a room. Any object on the other side of the globe, appears magnified, when viewed through it, for the reason that the gas-flame appears of the whole size of the apothecary's globe. Any object, which is in the right line passing through the middle of the globe and the eye, appears thus magnified, because the rays from it encroach on those from other objects. We cannot obtain an enlarged view of one object without partially or altogether obscuring the rays from another; and thus what we gain in one way we lose in another. If we look at the flame of a candle through a common decanter filled with water, we see that it is magnified in dimensions. This is due to the approach of the decanter to the globular form. A sphere has a circular appearance, when viewed in any direction; a decanter is circular in one direction at least, and therefore presents an enlarged, but not symmetrical, view of the candle.

50. It may now naturally be supposed that, if the two surfaces of the interposed body be curved spherically, though the whole body should not be a perfect sphere, results would follow, more or less similar to those which attend the use of a perfect globe. Such is really the case: a great thickness of glass is a detriment, rather than an improvement, if the design be to attain a magnified view of the object. Accordingly, in practice, the glass is moulded or ground into a flattish form, one or both of whose surfaces are spherical. This being done, the law of the sines, which we have explained, becomes the source of a very extensive range of effects; which will come under our notice in the article on the Telescope.

51. Thus, then, we have endeavoured to trace the progress of rays of light under different circumstances, without involving ourselves in any particular hypothesis as to the real nature or constitution of light. In the first place, we find that rays of light from a candle, or other luminous source, proceed in every direction from it, as from a centre, and that those rays pass in straight lines. 2ndly, That if an opaque, but polished, body be so placed as to receive some of the rays obliquely, these rays are reflected from its surface at angles equal to the angles, which they make in approaching. 3rdly, That, if the reflecting surface be a segment of a regularly curved body, as of a sphere, the effect of the last stated law is to diminish the apparent size of the object, if the surface of reflexion be convex, and to increase it if it be concave. 4thly, That, if a plate of glass be interposed between the object and the eye, such object will appear of its proper form and dimensions, provided the two surfaces of the glass be parallel; but, if any deviation from parallelism exist, the object will appear distorted either in position, form, or dimensions; the nature and amount of such distortion being regulated by the laws of refraction. Lastly, we have seen, that, when the operation of this law has reference to a solid globe or other curve, a remarkable increase of light is experienced at a particular point, which increase entails a diminution of light at other parts.

The point, where light converges, on the side of the refracting substance away from the source of light, is called the *focus*; which is Latin for a *hearth*, or place where fire or heat is collected.

We now proceed to another important property of light, more immediately connected with the Prism; which is the subject of Chromatics.

Section II. On Chromatics *.

52. The poet of the Seasons says, in apostrophizing light,

Nor to the surface of enliven'd earth,
Graceful with hills and dales, and leafy woods,
Her liberal tresses, in thy force confined :
But, to the bowel'd cavern darting deep,
The mineral kinds confess thy mighty power.
Th' unfruitful rock itself, impregn'd by thee,
In dark retirement forms the lucid stone.
The lively diamond drinks thy purest rays,
Collected light, compact.
At thee the ruby lights its deepening glow,
And with a waving radiance inward flames.
From thee the sapphire, solid ether, takes,
Its hue cerulean ; and, of evening tinct,
The purple streaming amethyst is thine.
With thy own smile the yellow topaz burns.
Nor deeper verdure dyes the robe of Spring,
When first she gives it to the southern gale,
Than the green emerald shows. But, all combined,
Thick through the whitening opal play thy beams ;
Or, flying several from its surface, form
A trembling variance of revolving hues,
As the site varies in the gazer's hand.

Poetry never shines with so bright a lustre as when it borrows its images from Nature, and corrects the exuberance of Imagination by the accuracy of Science. It is a mistaken notion to suppose that Science restrains the language of Poetry. Many illustrious examples prove that its aid tends to exalt and refine the children of Fancy, by clothing them in the garb of Truth. We all feel that the beautiful becomes more touching and effective, when regulated by the principle of truth ; and as this principle is unlimited in its application, the poet and the philosopher may recur to their respective pursuits, for that aid which the study of a perfect model, common to both, affords. It is delightful to meet with a poet who can understand and appreciate true science, and apply its resources in aid of his most beautiful productions. Such a poet is Thomson, whose writings abound in scientific allusions, and his application of them shows how well he appreciated the mental powers of the great Newton :—a man, who indeed deserves the exalting encomiums of poetry, although it is probable that the student of science only can justly estimate his worth. In the present section of the Prism, and in the two following articles, we shall have an opportunity

* This word is derived from χρωμα, the Greek for *colour.*

of studying some of the most beautiful phenomena of science, as discovered by the illustrious philosopher, to whom we have just referred.

53. In the preceding section, we have seen that a ray of light, if it meet an interposing body in its progress, is either transmitted through that body, or reflected from its surface, according to the extent to which the interposing body possesses the property, called *transparency*. But we have not yet considered light as the vehicle, or cause of *colour*, since the phenomena of reflexion and refraction admit of explanation without reference to colorific properties. We will, therefore, in order to obtain a clear view of the nature and origin of colour, proceed to the discussion of the subject in this order:—

i. The means by which Newton discovered that white light is a compound calorific body.

ii. The application of that discovery to the explanation of the colours of natural bodies, and of other phenomena in which colour is concerned.

54. Before the time of Newton, nothing certain was known concerning the origin of colour; that it was connected in some way with light, was very clear; but the nature of that connexion was by no means understood. Newton, however, found that a beam of white light, such as we derive from the sun, is composed of rays of different colours, each colour possessing a degree or power of refrangibility peculiarly its own.

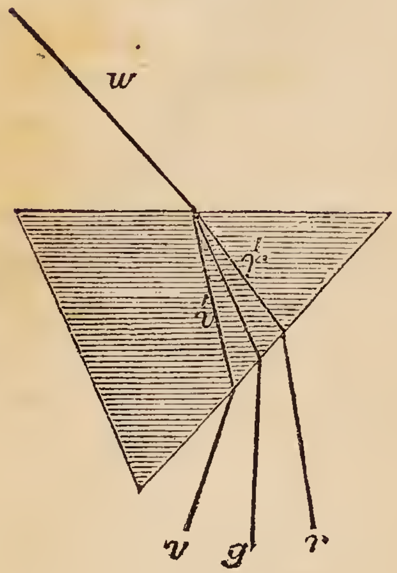
55. The instrument, by which this grand discovery was accomplished, is that which forms the title of the present article; viz., the *Prism**. A prism is an oblong piece of glass, or other substance, with three or more faces ground upon it. The number of faces in a prism used for optical purposes is *three*; and such a prism presents an appearance, which may be seen in section, at P or Q, fig. 17.

56. In order to understand the action of a prism we must call to mind the effect of the refraction of light through a piece glass, whose two surfaces are not parallel: see fig. 11. We found, that with such a piece of glass, the light was refracted at the first surface and also at the second surface; but that the second refraction did not bring the ray into a direction parallel with the incident ray, as was the case when the surfaces of the glass were parallel; it being permanently bent into another direction. It is manifest, then, that we may assimilate the prism with a plate of glass, whose surfaces are not parallel;

* This word, which is from the Greek, implied originally, a *segment* of any body, cut off by a *saw*.

and that we may expect a permanent deviation, by its means, in the direction of a ray of light.

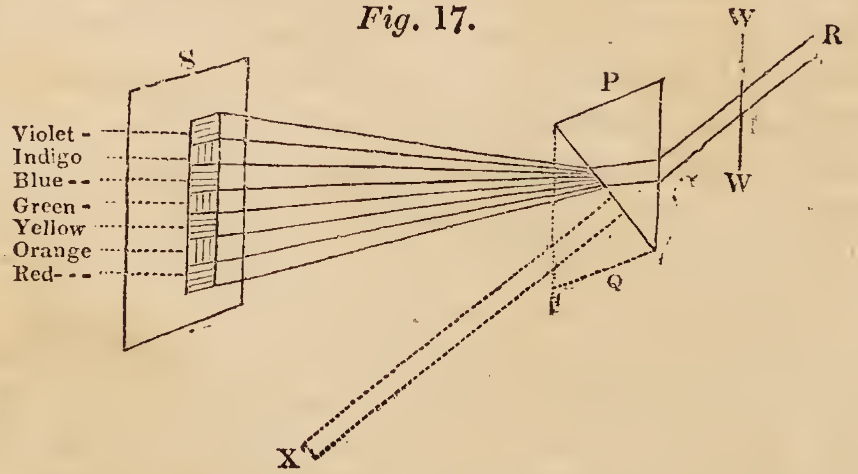
Fig. 16.



57. Let us suppose that we have a prism, in a horizontal direction, with one end towards the observer, as in the following figure, (fig. 16). A ray of light, *w*, impinges obliquely on the upper surface, and is there refracted out of its original direction, nearer to the perpendicular. On emerging from the second surface, it is further refracted into the direction, *g*, which deviates still more from the original direction.

It will, however, be found that this is not the only effect produced. Although the ray enters the prism as an (apparently) individual ray of white or colourless light, it is separated by the first surface into different portions, of which r' v' are the extremes. On leaving the second surface, they are still farther separated,—the central portion of the ray being represented by *g*, and the exterior portions by *r v*. Not only is the incident ray thus separated into smaller rays, but these become *coloured*;—for instance, the three letters, *r*, *g*, *v*, signify *red*, *green*, and *violet*: those being the colours of the three rays which our figure represents.

Fig. 17.



58. The manner in which Newton observed this phenomenon, was as follows:—He closed the door and windows of an apartment, so as to exclude the light. He then made a small hole in the window-shutter, W W, (fig. 17,) in front of which he placed a glass prism, P, with one of its angles downwards; and at a considerable distance behind the prism, he placed a white screen, S, on which the refracted rays

might fall. Now, if there had been no prism interposed between the hole and the screen, a circular bright spot of white light would have been made by the ray, R at x; but, as two refractions are produced by the prism, the refracted ray is bent upwards towards S. Here, however, the refracted image is not a circular spot of colourless light, but an oblong image, resplendent with various hues. The breadth of this image, or spectrum, does not much exceed that of the hole in the window-shutter; but its length is far greater. At the upper end appears a pale lively violet colour, which changes by a gradation of tints into indigo, and blue: the latter melts into a green tint, and this to yellow; then follows orange; and the last, at the base of the spectrum, is a brilliant red. All these colours are of surpassing brilliancy; such, indeed, as the pencil of art endeavours in vain to imitate;—

For who can paint
Like Nature? Can imagination boast,
Amid its gay creation, hues like hers?
Or can it mix them with that matchless skill,
And lose them in each other, as appears
In every bud that blows?

59. In order to account for this production of an oblong coloured spectrum, instead of one that is circular and colourless, Newton conceived, that a ray of light, which we call *white*, is not in reality one individual ray of a white colour; but that it is compounded of seven different colours; and that, when these several colours are mixed in due proportion, they neutralize each other, and present no appearance of colour whatever. In order, likewise, to account for the decomposition of that light by the prism, and for the oblong form of the spectrum, he conceived that the different component rays have different indices of refrangibility, or different powers of bending from their incident direction, on entering a refracting substance. When treating of refraction generally, without reference to the production of colour, we found that the amount of bending, experienced by a ray, depends upon the nature of the substance through which it passes; but, in the case before us, we have the medium (the glass prism) remaining the same; and yet we find that the capability of some component rays to be refracted is greater than that of others. This was Newton's idea of the formation of the coloured spectrum; and, in order to test its accuracy, he adopted a converse experiment, with a view to refract the different component rays into one circular bundle. If, in so doing, it should appear that colour was extinguished,

he considered that the truth of his theory would be established. For this purpose he placed two prisms face to face, in such a manner, that the apex of one prism was directed downwards, and that of the other upwards. This second prism is represented by the dotted triangle, Q, (fig. 17). It was now found, that, the corresponding angles of the two prisms being equal, the coloured light, produced by the first prism, was completely obliterated by the converse refraction of the second; that is, any refraction and consequent separation of colour, by means of the first prism, was corrected by the effect of the second prism; and the combined action of the two was nearly the same as would have resulted from the interposition of a piece of thick plate-glass, whose opposite sides are parallel.

60. The extinction of colour is also attended with the correction of refraction in the case of the second prism; so that, if, for any purpose, a refracted colourless ray were required, these two prisms would not produce it, because the operation which removes the colour, removes also the refraction. But it has been found of late, that a certain degree of refraction may exist, without the presence of colour, by employing two prisms of differently refracting powers; one of which forms the coloured rays, produced by the first prism into a beam of white light, but without altogether neutralizing the refraction of the first prism.

61. When Newton had separated the beam of white light into its component coloured parts, he further tested the truth of his theory, respecting such decomposition, by refracting the different coloured portions separately through another prism, which was not placed, as in the preceding experiment, close to the first prism, but at such a distance from it as to enable him to operate on any one colour singly. To do this more effectually, he devised a mode of excluding those rays, which were not the subject of experiment, in order not to vitiate the results, which he might obtain. For this purpose, he employed a second screen between the two prisms; and through a hole in the first screen, he allowed any ray, on which he wished to make observations, to pass, without its being accompanied by rays of another colour. There were, then, four parallel surfaces, or planes;—viz., the window-shutter,—two screens,—and the wall of the room. A small hole was made in the window-shutter, and similar small holes in the two screens; one in each. A prism was placed just behind the hole in the window-shutter, and another prism between the second screen and the wall. A beam of the sun's light was then permitted to enter through the hole in the window-shutter, and to impinge on the anterior surface of the prism. It was thereby refracted,

or expanded, according to the refrangibility of the different coloured rays of which the beam was composed; so that, when these arrived at the second surface, the beam gave a larger sectional area than when it entered the first surface. On emerging from the second surface of the prism, this divergence was increased: the blue or violet rays became separated from the orange and red; the former being the most elevated in position, in consequence of their greater refractive power. Thus, by the time that the beam arrived at the first screen, a spectrum was formed, blue at the upper and red at the lower end, but not very much elongated, because the screen was placed near the prism.

62. The hole in this screen was so arranged as to permit only one of the coloured rays to pass through it. As, however, the coloured rays had not space sufficient to separate completely from each other, and other rays might have been mixed with the one in question, the hole in the second screen was made of such a size as to admit but a portion of the ray, which passed through the aperture of the first screen. This ray was then refracted by the second prism, placed behind the second screen, and carried upwards. Here a remarkable circumstance was observed. The beam of coloured light was not elongated, as the decomposed beam of white light was, but remained of the same form as the aperture in the second screen. By turning the first prism gently round on its axis, all the coloured rays in succession, were made to pass through the holes in the screens, and to form small circular spectra on the wall, the highest of which was the violet, and the lowest the red.

63. This experiment showed to Newton, that a beam of light will suffer refraction as often as it meets with changes of media; but that an elongation of its form only takes place when rays of different colours are contained in the beam; the form being unaltered so long as the beam consists of *homogenous* light, *i. e.*, light *of one colour.* The cause of the elongation in the form of the spectrum, is the varying refrangibility of rays of different colours; and it appears from this experiment that there is a degree of refrangibility, belonging to each colour, differing from that of the others. Yet, when we regard the melting of one into another, it seems to show that the indices of refraction of the different rays increase gradually, and by minute increments, from the red to the violet; and do not differ by abrupt steps from one tint to another. In practice, however, it is usual to consider the mean, or middle ray of each colour, as the symbol of that colour, and to assign its refractive index as that which belongs to the colour.

64. Another method by which Newton convinced himself that white light is composed of the colours already enumerated, was by allowing the decomposed rays to pass through a double convex lens, by which they became again converged, and presented the appearance of a spot of white light. Now, in speaking of the refraction of a ray of light by a globe of glass, we showed that, if rays, emanating from a luminous object, impinged upon the anterior surface of the globe, they would be refracted by the globe, and converge to a point or focus on the opposite side; and also that, if two spherical surfaces, such as two slices of a globe, were placed face to face, and presented to the rays, an effect would take place, similar to that with the globe of glass. Now a double convex lens may be considered to be two slices of a sphere, placed face to face. The divergent rays, as they leave the second surface of the prism, are brought into directions nearly parallel with each other, while in the body of the lens: which parallelism is changed into convergence, as they emerge from the posterior surface of the lens. Newton found that, although, at any point between the prism and the focus, the beam of light was divided into different colours, yet that, *at* the focal point, the collected rays acquired their original character of *white light.* This process also showed, by decomposition and recomposition, that white light is composed of rays of various colours.

65. Sir Isaac also proved the different refrangibility of different rays, in another manner. He took an oblong piece of black paper, and divided it into two equal parts; the one part he coloured with red, and the other with blue. He then carefully excluded all the light from the apartment, and before the window on a table he placed the coloured paper, the line dividing the colours being perpendicular to the plane of the window. He then held a prism with one of its angles upwards; so that the light coming from the paper was twice refracted before reaching the eye. On viewing the paper through the prism, he found that the blue half of the paper appeared more elevated than the red half,—thereby indicating that the blue rays were more refracted than the red; which experiment accords with the other results.

66. When, in any scientific researches, a result has been arrived at analytically, it is always desirable to determine whether the converse can be obtained synthetically. The difference between *analysis* and *synthesis*, is similar to that between taking to pieces, and putting together again; the former being decomposition, and the latter recomposition. When, by means of galvanic or chemical processes, we resolve water into its

elementary gases, oxygen and hydrogen, and find no other material, we ascertain the composition of water *analytically;* but, if we mix together the two gases, in such proportion as analysis has revealed to us, viz., two volumes of hydrogen gas, and one volume of oxygen, and can, by any agency, such as flame, the electric spark, or intense pressure, convert this mixture into water, without leaving any residue of the gases,—then we determine *synthetically* the composition of water. In the former case, we *resolve* it into its elements; in the latter we *compose* it by combining those elements.

67. Now, this reasoning may be applied to the processes for determining the composition of light. We have seen how light is analyzed, and its compound or colorific elements revealed. It is, therefore, desirable to determine whether white light can be produced by mixing artificially, light of different colours. The sagacious Newton did not lose sight of this mode of proof. He observed with great attention what appeared to be the respective proportions of each colour in the prismatic spectrum, and he procured seven different kinds of powder, the colours of which approached, as nearly as possible, to those of the solar spectrum. He took 80 parts of red, 45 of orange, 72 of yellow, 80 of green, 45 of blue, 45 of indigo, and 80 of violet; making 447 parts in the whole. These he mixed up well, and placed them in a heap on the floor of his room; and by the side of the heap of powder he placed a sheet of white paper. The room being darkened, a beam of light was admitted, so as to illuminate the powder, but not the paper. Viewing them from a distance, he could perceive no difference between the two,—both appearing to possess a similar whiteness. A person, happening to enter the room during the experiment, was requested to say whether he could perceive any difference in the whiteness of the paper which was in the shade, and that of the powder, which was in the sunlight. This person, who was not made acquainted with the nature of the powder, after viewing deliberately the two bodies, said, "That both were good whites,—that he could not say which was better, nor wherein they differed." It thus appeared that the only difference between the colour of the mixed powders and of the paper, was not so much in its hue, as in its brilliancy. We call a piece of paper *white*, whether we look at it in the gray light of morning, in the glare of noon, in the purple hue of evening, in the silvery light of the moon, or in the yellow light of a candle; and yet it is evident that there must be considerable difference in the actual appearance of the paper under each of these circumstances. We may, therefore,

consider the colour of the mixed powders under the like points of view, to be an impure white; and this impurity we may reasonably refer to the impossibility of determining the exact proportions of the different hues, and to the imperfection of each hue.

68. Another way of producing this result experimentally, is to divide a disc of card-board, or of tin, into seven compartments, by drawing radii from the centre to the circumference. In order to obtain the proper proportions between the several colours, we must make the angular dimensions of each compartment bear a ratio corresponding to the number of parts of the coloured powders: viz., 360 to 447. Newton had divided 447 into 7 unequal parts; and we must divide our circle of 360° into the same number of unequal parts; each of which must bear to the corresponding number in the case of the powders, the ratio which 360 bears to 447. Thus as 447 : 360 : : 80 : $64\frac{1}{2}$; so that $64\frac{1}{2}°$ is the angular measurement of the *red* compartment; and so on with the rest. We shall see, however, presently, that the proportions thus found, do not, in the present state of our knowledge, admit of very exact comparison with the colours of the solar spectrum. If now the disc be fixed to a wheel, and a rapid motion be imparted to it, the colours will be all blended, and form white, though somewhat impure; the homogeneity of the white increasing as the velocity of rotation increases*. The rationale of this experiment is, that, before the impression of the red rays has departed from the eye, the orange rays present themselves; and before the impression of those is gone, the yellow appear: next to them the green, blue, indigo, and violet, successively impart their respective tints to the eye. When the velocity of rotation is great, a whole circuit of the disc is performed before the impression of the first portion has left the eye, and thus there are seven different colours impressed upon the eye at one time; superposed one upon another. The combined impression, therefore, is made up of

* The Poet Crabbe has taken advantage of this experiment in the following excellent simile.

> "As various colours in a painted ball
> While it has rest, are seen distinctly all;
> Till, whirl'd around by some exterior force,
> They all are blended in the rapid course:
> So in repose, and not by passion sway'd,
> We saw the difference by their habits made;
> But, tried by strong emotions, they became
> Fill'd with one love, and were in heart the same;
> Joy to the face its own expression sent,
> And gave a likeness to the looks it lent.
>
> *Tales of the Hall. The Brothers.*

seven component impressions, and is found to present that of white light.

69. Such are a few of the very important results of Sir Isaac Newton's experiments with the prism. They enable us to account for a wide range of natural as well as artificial phenomena; which we should find it impossible to explain, but for the hypothesis that a beam of white light consists of rays of different colours, and that these rays admit of separation, and of being exhibited apart from one another. We now proceed to notice a few of these phenomena, before proceding with the subject of the Prism.

70. ii. *On the Colours of Natural Bodies.* There are few persons that have not felt delight in gazing upon

> . . . . . . each beauteous flower,

where

> Iris all hues, roses and jessamine,
> Reared high their flourish'd heads between, and wrought
> Mosaic; under foot the violet,
> Crocus, and hyacinth, with rich inlay
> Broider'd the ground, more colour'd than the stone,
> Of costliest emblem.

The vegetable world has furnished themes for the contemplation of poets and philosophers in all ages; while to those whose ruder minds cannot appreciate the beautiful in form, in colour, and in habits, there is still something in brilliant hues which excites admiration and pleasure.

71. On inquiring into the nature or cause of colour, the first fact presented to our notice is, that we cannot distinguish the colour of an opaque object, unless it be illuminated by light derived from without. A rose, a violet, and a lily, all appear of the same hue, when viewed in light, sufficient merely to enable us to distinguish their forms. If we take two pieces of cloth, a blue and a green, for example, into a well illuminated apartment, we can readily distinguish between them; but if we diminish the light, or view the specimens in the shades of evening, we find the distinction to be difficult, and often impossible. We may arrive at a degree of obscurity when even red cannot be distinguished from blue; and a certain point of darkness is soon attained when colours become altogether lost to the eye.

72. Such then being the case, we cannot avoid the conclusion, that the colours of natural bodies are dependant on the light by which they are illuminated, whether such light be directly from the sun, from a blue or a clouded sky, or from a flame. But we are now about to show that colour has no existence in the body itself, and that it only exists while light actu-

ally falls upon it: that when we regard a body in a dark room, it is not only true to say that we cannot see its colour, but it is also true, that such body has then no colour at all; or, if we call *black* a colour, then that such body not only appears to be, but is, absolutely black.

73. The surface of every body in nature has the property, more or less, of resolving a beam of light which impinges upon it into its different component rays, some of which are reflected from the surface, while others are absorbed by it, in a way which is not well understood; while sometimes the other rays pass through the substance, and emerge from the opposite side. In the case of a looking-glass, some of the rays of a beam of light, falling upon it, are reflected without decomposition at the front surface of the glass: a few are absorbed by the substance of the glass; and a small portion by the mercurial amalgam, which covers the hinder surface of the glass as a thin film:—but the greater portion is given off from the metallic surface, through the substance of the glass, into the room again; and it is by means of these reflected rays that we obtain a view of an object, as it is said "in the glass."

74. But, suppose the reflecting body is a surface of polished metal only, such as a piece of silver plate: in this case there is no transparent substance to be permeated by the rays of light; but these are nearly all reflected as soon as they reach the surface of the speculum. In these two cases the beam of light is separated into rays, which are reflected by different paths; but these rays have not been decomposed into their several colours; that is, chromatic decomposition has not taken place. When, however, the beam of white light is received on the surface of a speculum of gold, the circumstances become changed. The beam is then *chromatically* decomposed, and a portion of the coloured rays is reflected back to the eye; while the others penetrate the substance of the metal. It is by means of the yellow, or yellow and orange, rays that we see the golden speculum. We are not conscious, in beholding it, that white light continually falls upon its polished surface, and is as continually decomposed:—we know that a dazzling yellow light meets the eye, and we pronounce gold to be of the colour of that light. Thus it is with most of our perceptions: the information they afford to the higher powers of the mind, is immediate, almost instantaneous, without any reference to the means by which the observed phenomena are effected; and it is left to the slower faculties of reason and reflection, to trace analogies, to point out differences, and to assign the causes, of things.

75. It is found that the colours of bodies result from a property, common to matter generally, of resolving white light into its colorific elements. Those tints, which are reflected back from a surface, give a name to the colour of the object: thus, if a substance have the property of attracting or taking to itself all the coloured rays except the blue, then the blue rays will be reflected, and will determine us in calling the colour of the object *blue*. If all the rays except the red be absorbed or attracted by the substance, then red will be reflected to the eye, and the object is called *red*. For instance: a part of the flower of one species of the geranium possesses the power (but what that power is, and how acquired, we know not,) by which all the rays, except those constituting a brilliant scarlet, are absorbed by that particular part of the flower; the scarlet is reflected, and the eye receives from it that sensation of colour, which leads us to call the plant, *the scarlet geranium*.

76. Now we may suppose, for the sake of fixing our ideas, that each colour of the spectrum consists of minute particles or atoms, given off by the luminous body, and that these have either different velocities of motion, or different physical or chemical properties, by which they are calculated to produce various effects on any body whereupon they fall. If we take this preliminary view of the difference between the variously coloured particles, we may next suppose that the surfaces of opaque bodies have either interstices or variously constituted pores, which will admit some rays easily and exclude others altogether; or that there is an attraction exerted by the particles of that substance towards some rays in preference to others. As we do not lay this down as a *theory*, but merely give it as a convenient mode of comparing effects, it matters not which view we take of the operation in question; whether we suppose that some rays force for themselves a passage through the substances of bodies, which other rays, moving with less velocity, cannot accomplish, or that the particles of a substance exert an elective attraction towards some rays in preference to others.

77. It may now be inquired whether all the immense variety of colours of natural bodies is referable to seven colours only. Now, not only is this considered possible, but the number of *primitive* colours, in the opinion of most modern philosophers, is limited to *three*, viz., Red, Yellow, and Blue. It is supposed that by a mixture of two or more of these colours, in various proportions, all the colours of the universe are produced. If we had a quantity of pure water, and another quantity of proof brandy, it is clear that we can mingle the two together in such

proportion as to get any required degree of strength below the initial strength of the spirit: we may even get such a mixture that the water shall contain but a drop of the spirit, or the spirit only a drop of the water. The degrees of dilution, as will be at once conceived, may be almost infinite. Now it is believed that variations of tint are effected by somewhat analogous means. There may be two flowers, a yellow and a blue: one absorbs all the rays of light which fall upon it except the yellow; and the other absorbs all except the blue. But, suppose that we have a third flower, which rejects all the yellow and a small portion of the blue: these rays will intimately mix on leaving the surface by reflexion, and will yield a compound sensation, resulting from a large portion of yellow, and a small portion of blue.

78. It is a practice with artists to mingle different colours on their pallet in various proportions, in order to obtain a desired *shade* of colour. If, for example, a little blue be mingled with a larger portion of yellow, the immediate result is a yellowish green. A similar result is obtained by a mixture of natural colours: if the body on which light impinges, throw off or reflect blue and yellow rays simultaneously, the appearance of the surface of such body, is instantly recognised as *green*. If the amount of blue rays be increased, the green becomes bluer in the same ratio; and it will thus be seen that the number of shades of green may be as numerous, as the number of degrees of strength in the mixture of spirit and water before alluded to.

If instead of blue we take red, we have a new class of tints. The range of scarlet and orange colours, &c., are mixtures of various proportions of red and yellow light. When white is added to these colours we get lemon and straw colours, and we may produce browns by mingling black and orange in various proportions.

Mixtures of red and blue, and of these with white, form the varieties of crimson, purple, violet, rose-colour, pink, &c. The richer purples contain no yellow.

The primary colours are seldom met with in nature in a pure state. Arterial blood, moistened gamboge, and ultramarine, are the best examples of them. The scarlet of vermilion, and the vivid red of the sesqui-oxide of lead, contain yellow, and sometimes blue. Colours are increased in splendour by a certain mixture of white, provided such colours be transparent: but if the colour be opaque, the addition of white has the effect of dimming its splendour.

White and gray, in all their immense varieties, are called *neutral tints*, because colour is either absent or neutralized. The

various intensities of whiteness, as we observe them in the clouds, on an ordinary cloudy day, when sunshine occasionally gleams, are good examples of neutral tints. Even the bluest sky, as seen in England, is but blueish gray.

79. In the floral botany of this country we seldom meet with the primitive colours, except yellow; most of the tints being in a mixed state. We will give a few examples of flowers—which the student may meet with in his country-rambles at some season or other of the year; which flowers approach very near to the seven colours of the spectrum. The choice and arrangement of the following specimens, the author owes to the botanical skill of his friend Mr. John Lambert, of Salisbury.

Red. Anagallis arvensis, or red pimpernel. Indigenous.
Glaucium phæniceum, or red horn-poppy. Ditto.
Papaver Rhœas, or common corn-poppy. Ditto.

Of these three, the Glaucium is decidedly *red*; the Anagallis is more intense in colour; and the Papaver is between scarlet and red.

Orange. Calendula officinalis, or Common Marygold. Indigenous.
Buddlea globosa, or Buddlea. Introduced from Chili; but often seen in shrubberies.

These flowers are undoubtedly *orange*.

Yellow. Ranunculus acris. Butter-cup. Indigenous.
Lysimachia vulgaris. Loose-strife. Ditto.
Verbascum thapsus. Mullein, or Shepherd's club. Ditto.

Green. Erica viridiflora. Green-flowered Heath.

We have probably no flower, except a few very insignificant indigenous ones, which is green, except this heath, the flowers of which are *greener* than its foliage. It is not indigenous, but an introduction from the Cape.

Blue. Centaurea cyanus. Blue-bottle; indigenous. } Found in Corn-
Veronica spicata. Spiked Speedwell; ditto. } fields.

But the first of these is too light, the second too dark, for a decided blue.

Indigo. Polygola vulgaris. Milk-wort. Downs. Indigenous.

This is the only flower that approaches at all to *indigo*. It is not dark or thick enough in colour; but masses of flowers at a short distance possess somewhat the tint of this colour.

Violet. Viola odorata. Common blue Violet.

This flower is certainly of a *violet* colour; some of the Campanulas, or Canterbury-bells, are nearly violet.

Few of our coloured flowers possess perfume, but nearly all white flowers do: for it is most palpable that, where Nature is

sparing of brilliancy of colour, she supplies the deficiency by the alluring property of perfume.

80. We have hitherto considered only the rays, reflected from the surface of such bodies as are capable of decomposing chromatically the light which impinges on them. We must now consider that portion which penetrates the surface, and enters into the substance of the body.

If we regard the surface of gold, we perceive it to be of a brilliant yellow hue; and we likewise see that its colour is as decided when the thickness of the gold is very small, as when it is great. A sheet of leaf-gold is not more than $\frac{1}{180000}$th part of an inch in thickness; and yet it presents a perfectly brilliant yellow to the eye. But if we hold it up, so as to be able to see the transmitted light, we shall find its colour a dark or subdued *green*. If we take a leaf thicker than the former, we shall see in this case, that the shade of the green is deeper and duller; and we may soon arrive at a degree of thickness, which excludes the light altogether.

81. We here get something like proof, that the white light, which falls on the surface of the gold, is, by it, decomposed into its colorific elements, some of which are reflected from the surface while others penetrate through the substance of the gold, and emerge at the other side. The colour, which is reflected, is not exactly a pure yellow, but it partakes of the characters of yellow and red; while the transmitted colour partakes of the combined character of yellow and blue. If, therefore, we suppose that some of the red rays are absorbed by the substance, so as to be neither reflected nor transmitted, we might perhaps account for the distribution of all the rays which fall upon the gold: a portion of the red is absorbed,—another portion of the red combines with the greater part of the yellow, to form the reflected *gold* colour; and the remaining part of the yellow combines with the blue, to form the transmitted green. We do not aver that this is a true exposition of what occurs; but it is in such a way that the different colours are to be accounted for. Experiments prove, that, in every instance, some of the rays of light which fall upon a body are absorbed by it; but *how* is not known. If we examine a piece of black velvet, we find scarcely any reflexion from its surface. Black is considered as synonymous with entire absence of colour, and indeed, of light. If we hold the velvet between the eye and a candle, we perceive a few traces of light through it; but in comparably less than the quantity of light which falls on its surface. If then, we find that a large portion of light falls on the surface;—that only a minute portion passes through;—and

that a still smaller quantity is reflected, we must conclude that the light is absorbed, or stifled, in passing through the substance of the body. Bodies are dark in proportion as they absorb light. A room hung round with black cloth or velvet, and a coffin, on which is shed the light of wax-tapers, is an impressive spectacle. The light, falling upon the cloth or velvet, is absorbed; and the feeling of gloom arises from the circumstance that nothing seems to reflect light. Whereas, in a room, whose sides are covered with mirrors, reflecting the various lights; where music and merry voices mingle in concert, how different is the scene! Even in the absence of human beings, and especially happy and innocent ones, whose presence blesses and enlivens almost every scene,—the room yet appears cheerful, in consequence of the abundance of reflected light, the absence or absorption of which is, in general, attended by a gloomy prospect.

82. Were it not for this absorption, we should always be able to say what colour, joined to a transmitted colour, would make white light; because it would be precisely the colour reflected from the same body. In some cases we are enabled to do so to a certain extent; as, for example,—If we procure a piece of stained glass of a light green colour, and place it upon a piece of looking-glass, and incline the two towards the light, so as to get some object reflected, we shall observe two images, a green and a red; the latter, however, diluted with white. The green image is from the looking-glass, and is green in consequence of passing through the green glass to the eye;—while the red image is obtained from the exterior surface of the green glass, and is the residual portion of the light which did not enter the glass: but, as other white light falls upon the green glass, and is simply reflected without decomposition, the red of the light which is decomposed is diluted by the reflected white light. Of the light which enters, a portion of the rays of one or more colours is absorbed by the substance of the glass.

83. When coloured rays are combined in two different tints, so that the mixture produces white light, they are said to be *complementary* to each other; one being the complement of the other. Thus, blue and yellow make green, which is the complementary colour to red; and the three together make white light. Red and yellow make orange, of which blue is the complement; and so on. If, therefore, light were decomposed into only two portions by transparent media, one portion being completely reflected, and the other completely transmitted, we should be enabled to tell precisely the complement to any

colour, or combination of colours, by referring to the transmitted ray, if the observed ray be reflected; or to the reflected ray, if the observed ray be transmitted. But the varying effects of absorption often prevent our doing so with accuracy.

84. The subject of complementary, or, as they are sometimes termed, *accidental* colours, admits of much amplification, for which we have not here sufficient space. These colours can be seen by placing variously coloured wafers in succession upon a white ground,—such as a sheet of white paper,—and viewing each wafer steadfastly for a minute or two; a ring will soon begin to play around the wafer, of a colour complementary to that of the wafer itself. Again, if we close one eye, and place before the other a piece of coloured glass, (*green*, for instance,) and through this medium view a sheet of white paper, the sudden removal of the glass from the eye, will cause the paper to assume a red appearance:—or, if the observer regard a taper, in a room where there are no other lights, through a pair of coloured spectacles, the sudden removal of them will impart to the flame the complementary colour of the glass of the spectacles.

Complementary colours can be most instructively studied by means of *coloured* shadows, or shadows *thrown into coloured light*. These may be obtained by passing natural or artificial light through transparent coloured media,—by coloured flames,—or by reflexion from coloured surfaces. When a shadow falls into a coloured light, it becomes complementary in colour to the light into which it falls, provided such shadow be illuminated by light which is not coloured. Thus, if we employ two candles to cast the shadow of an upright rod, or other object, upon a white screen, and hold before one candle a piece of coloured glass, (taking care to remove the candle which is not covered to a greater distance, in order to equalize the depth of the two shadows,) we shall find that the shadow cast by the covered candle, is of the colour of the glass, and that the shadow cast by the other candle is its complement. Thus, if green glass be employed, the two shadows will be green and *red;* if red glass be employed, one shadow will be red and the other *green;* and so on. These beautiful experiments may be varied to any extent.

85. It is usual to say that shadows cast by the sun, and by strong artificial light, are black; and in some cases, they certainly appear so, because our usual criterion, *contrast*, is simple and imperfect. The unaccustomed eye is wont to view a shadow solely with reference to the surrounding light, and

decreasing light conveys more or less to the mind impressions of obscurity or darkness, since the depth of every shadow depends upon the greater or less absence of surrounding light. We have said that a shadow, falling into coloured light, assumes an opposite tint. This principle has been long recognized in practice, for the shadows in the pictures of the old masters are never black, but are variously coloured, as circumstances, or rather as Nature, requires. The only black shadow that we can conceive is one cast by white light, passing through a transparent colourless medium, and falling upon white ground; the shadow in such case, were it possible to attain to such perfection of observation, would even then not be quite black, but grayish, from the admixture of a small quantity of white light with the black of the shadow. The solar rays, passing through the blue ether acquire a yellowish tinge, and their shadows are generally blue or indigo, unless intercepted by the splendidly tinted clouds of morn or eve, which transmit light of their own peculiar colours, and afford shadows of opposite tints to themselves; and these colours vary in intensity, as the altitude of the sun varies, and are again modified by the colour of the ground upon which they fall. The effects of early morn, are, as artists term them, *cold;* when the tints and shades gradually merge from gray, and pass through various admixtures of yellow, green, and blue, into indigo; which latter, during the day, deepens into an apparent black. Evening brings its *warm* effects; the yellow merges into orange, by the presence of red rays; and the red, dark purple, and indigo, with their oppositely tinted shades, (always modified by the ground upon which they fall,) contribute to impart that richness or mellowness to the landscape, the successful imitation of which is one of the elements which constitute good painting. As the shadows of evening lengthen, they will generally be found to be indigo, if received upon white ground. Twilight, assisted by a moderate artificial light, is a very favourable time for observing the coloured shadows and opposite tints of nature. By night, the shadows cast by artificial lights, are seldom capable of being estimated, on account of their intensity; but by twilight they are distinctly seen to be either blue or indigo, and sometimes purple. By the yellow light of a lamp, just after sunset, the sky, as seen through the window, is of a very rich indigo: if a sheet of white paper be so arranged as to receive the light of the lamp and at the same time the natural light from the window, and the finger or other object be held so as to throw a shadow upon the paper,—two shadows will be obtained, one of bright yellow, and the other

of a rich indigo: this is a simple and familiar instance, and its explanation is no less so. The paper is illumined by the yellow rays of the lamp, and at the same time by the indigo rays from the sky: the former, by their intensity and abundance, overcome the latter, and the paper appears yellow: a shadow cast by the lamp deprives that portion of the paper occupied by such shadow, of the yellow rays; the shadow is therefore illuminated by the indigo rays of the sky. A converse arrangement will account for the appearance of the yellow shadow, which is cast, not by the lamp, but by the natural light falling upon the ground, illuminated by artificial yellow light and natural indigo light; except where the yellow shadow appears, for there the indigo is intercepted by the opaque object. These effects of coloured shadows merit much more attention than they have received. We now revert to the natural colour of bodies.

86. The cause, then, of colour, in nature, is to be found in the decomposition of light by the various bodies upon which it falls. A body is coloured, because it absorbs or transmits one or more colours, and reflects the remaining colours from its surface; and it is either by the transmitted or by the reflected colour that we name a body. If light were not composed of variously coloured rays, there would be no such thing in nature as variety of colour; all objects would be of precisely the same colour, and the gay and diverse landscape would become a monotonous wilderness; human features would be devoid of beauty:—the smile of intelligence would be ghastly:—the eye would find no resting place, and the mind no occupation. On the other hand, if white light were composed of rays of the same refractive power, it would be equally acted on by all bodies upon which it fell, and then "all Nature would have shone with a leaden hue, and all the combinations of external objects would have exhibited no other variety but that which they possess in a pencil sketch, or a china-ink drawing. The rainbow itself would have dwindled into a narrow arch of white light,—the stars would have shone through a gray sky,—and the mantle of a wintry twilight would have replaced the golden vesture of the rising and the setting sun." It follows, therefore, that the colours of natural bodies can only be displayed in white light, constituted as it is at present. The light of our lamps and candles, is composed of rays of various degrees of refrangibility; but one set of rays (the yellow) is in excess. Hence, the remark is common, that "blue appears green by artificial light;" and it does so because the yellow light, by mixture with blue, forms green: it is notorious also,

that colours cannot be discriminated by artificial light. But, supposing that a room is illumined by light of one colour only, which, of course, has a degree of refrangibility peculiar to itself:—suppose it to be a homogeneous red light:—then objects of a red colour will appear more intensely red than ever, and it is obvious that every object, whatever be its colour in natural light, can possess either no colour at all, or only one colour, in this light; and such colour is red. A leaf, which is green by day, because it has the property of reflecting green light in greatest abundance, cannot appear green in homogeneous red light, because there is no green light to be reflected; but it reflects a portion of red light, since there is some red in the compound green which it has the property of reflecting. But such bodies as do not possess the property of reflecting red at all, either in its simple or combined state, would appear absolutely black in pure red light, because the nature of such bodies is not so constituted as to reflect red light; and as there is nothing else to be reflected, they must necessarily appear black. If we hold towards the light a pot of red-lead, and cover it with a piece of green glass, the *red*-lead will appear like *lamp-black*, so completely is it prevented from reflecting rays of its own colour.

87. We have spoken of homogeneously coloured light, or light composed of one colour only, without any admixture of rays of another colour; but we must now observe that the colours of the spectrum, admirable and beautiful as they are, are not homogeneous; that is, they are not pure colours. If we take the three colours of the spectrum, red, yellow, and blue, it is easy to imagine that the intermediate orange is formed by the overlapping of the red and yellow; and the green by the overlapping of the yellow and blue: but modern science supposes that the whole spectrum is composed of three primary spectra superposed upon each other, of equal extent, but differing in intensity at different points. This view of the constitution of the spectrum belongs to Sir D. Brewster; and the means by which he arrived at it we will state nearly in his own language.

88. Although we cannot separate the green rays of the spectrum into yellow and blue by the refraction of prisms, yet if we possessed any substance which had a specific attraction for blue rays, and which stopped them in their course, while it allowed the yellow rays to pass, we should thus analyze the green rays as effectually as if they were separated by refraction. This property is found to exist in the purplish blue glass, similar to that of which finger-glasses are made. When the prismatic spectrum is viewed through a piece of this glass about one-

twentieth of an inch thick, it is found to exert an extraordinary absorptive action on the different colours of such spectrum. The red part is divided into two red spaces, separated by an interval entirely devoid of light. Next to the inner red space, comes a space of bright yellow, separated from the red by a visible interval. After the yellow comes the green, with an obscure space between them; then follows the blue, and the violet, the last of which has suffered little or no diminution. Now it appears that the blue glass has absorbed the red rays, which when mixed with the yellow on one side formed orange, and also the blue rays, which when mixed with the yellow on the other side formed green; so that the insulation of the yellow rays, thus effected, and the disappearance of the orange, and of the greater part of the green light, proves that the orange and green colours in the spectrum are compound,—the former consisting of red and yellow rays, and the latter of yellow and blue rays of the same refrangibility. If we compare the two red spaces of the spectrum, seen through the blue glass, with the red space seen without the blue glass, it will be obvious that the red has experienced such an alteration in its tint by the action of the blue glass, as would be effected by the absorption of a small portion of the yellow rays; and hence we conclude that the red of the spectrum contains a slight tinge of yellow, and that the yellow space extends over more than one half of the spectrum, including the spaces occupied by red, orange, yellow, green, and blue.

89. It has been found that red light exists in the yellow space, and that in the violet space red light exists in a state of combination with the blue rays. By examining the spectra produced by various bodies, and the changes they undergo by absorption when viewed through various coloured media,—Sir D. Brewster found, that the colour of every part of the spectrum may be changed, not only in intensity, but in hue, by the agency of particular media. Hence it was concluded that the prismatic spectrum is composed of three different spectra, viz. *red*, *yellow*, and *blue*, all having the same length, and all overlapping each other. Hence red, yellow, and blue rays of the very same refrangibility co-exist at every point of the spectrum; but the colour at any one point will be that of the predominant ray, and may be considered as the predominating colour, mixed with white light. In the red space there is more red than is necessary to make white light, with the small portions of yellow and blue, which exist there; in the yellow space, there is more yellow than is necessary to make white light with the red and blue; and in the part of the blue space which appears violet, there is

more red than yellow, and hence the excess of red forms a violet with the blue.

90. By absorbing the excess of any colour at any point of the spectrum, above what is necessary to form white light, such white light will appear at that point, as Mrs. Somerville remarks, "as never mortal eye looked upon before this experiment," since it possesses the remarkable property of remaining white after any number of refractions, and of being decomposable only by absorption.

91. We come now to notice a very remarkable fact connected with the prismatic spectrum. In 1802, Dr. Wollaston discovered, that, when the spectrum is formed, a very narrow line of light being its origin, the coloured spaces appear crossed by several parallel dark bands. In 1819, M. Joseph Fraunhofer, a distinguished optician of Benedictbaiern, near Munich, in Bavaria, without knowing of Dr. Wollaston's discovery, noticed the same fact, but with superior apparatus. In order to see these lines distinctly, it was found necessary that the light should enter and emerge from the prism at equal angles. By examining the spectra formed by various solid and fluid bodies, he not only discovered that they all possessed the same lines, but that these lines had fixed positions with respect to the different colours;—the distances between the lines in different parts of the spectrum thus affording precise measures of the action of the prism on the rays forming the corresponding coloured spaces.

92. To see these lines distinctly, it is necessary that the prism be formed of the finest flint-glass, perfectly free from specks and veins;—that all extraneous light be excluded;—and that the spectrum be viewed through a telescope.* We give a

* As the reader may not have the command of suitable apparatus, we give a simple plan, by which the dark lines may be viewed by any one possessing a prism of flint-glass, one of whose angles is from 70° or 78°. Into a bottle of white glass put about half an ounce of nitric acid, diluted with the same quantity of water. Then throw in some shreds of copper: —a gas called binoxide of nitrogen will soon be formed from the decomposition of the nitric acid. This gas, coming in contact with the air in the bottle, will be converted into the red vapour of nitrous acid. When the bottle is full of this vapour, turn out the contents and stop the bottle with a glass stopple ; (a cork will be corroded). Then procure a small sheet of metal, and cut a narrow strip out of it. Fasten this over the hole of a window-shutter, the slit being horizontal. When the shutters are closed, the white light of day will enter through the slit, before which, and close to it, the bottle of nitrous acid vapour is to be placed. If now the light be viewed with the large angle of the prism, kept close to the eye, the lines will be seen very distinctly.

few of these lines, in order to explain the purposes to which M. Fraunhofer applied the discovery. They are very irregularly dispersed over the length of the spectrum; in some places many lines are collected into a small space, while in other places they are wider apart: some of the lines are exceedingly faint, while others are strongly marked. But there are eight places in the length of the spectrum, which afford convenient boundaries for divisions into parts by presenting some prominent features, which distinguish them from surrounding lines, in consequence of each one being connected with a particular colour; although none of the lines coincide with the boundaries of the colours. These have been carefully noted and agreed upon by philosophers, and are represented in fig. 18, where R V represents the

Fig. 18.

elongated spectrum as cast by a prism, and A B C D E F G H the lines which serve to divide the whole length into separate portions. These lines, it will be perceived, are at very different distances from each other. Between these lines others are situated so thickly, that the number of the whole amounts to about 590. The following is the distribution of them:—

At A a well defined dark line within the red space . . .	1
At B there is a thick line, and one which is fainter . .	2
Between the end of the spectrum and B a mass of about .	8
At C a broad black line beyond the middle of the red . .	1
Between B and C	8
At D a strong double line in the orange. The two lines are nearly of the same size and separated by a bright one	2
Between C and D	30
E is in the green, and consists of several, the middle one being the strongest. Between D and E there are .	84
At F there is a very strong line in the blue and between E and F	79
G is in the indigo, and between F and G	185
H is in the violet, and between G and H	190
Making in all about	590

93. These lines are always found in spectra obtained by every kind of solid and fluid bodies; and although the lengths of different spectra vary considerably, as well as the proportion of

their coloured spaces, yet the *fixed lines*, as they are called, preserve the same relative position to the boundaries of the coloured spaces. Their proportional distances vary with the nature of the prism, by which the spectra are produced. If F, for example, corresponds with the centre of the blue in a spectrum produced by one kind of prism, such line will also correspond with the centre of the blue in a spectrum produced by another kind of prism; and, provided solar light be employed, the number, order, and intensity, of these lines, are invariable.

94. But we have further to remark that the spectra cast by prisms of different materials vary in their colorific properties. The developement of colour in any spectrum depends upon the substance, of which the prism is formed. If we take two prisms, one of solid glass, as before described, and the other formed of two plates of glass placed together at an angle, so as to form a kind of trough, in which liquid can be placed, and if we fill this trough with oil of cassia, we shall find that the spectra presented by these two prisms will be very different. The spectrum resulting from the latter will be two or three times as long as that which results from the solid glass prism. To obtain a convenient term for distinguishing this difference of length, we say that the *dispersive power* of oil of cassia is greater than that of solid glass; by which we mean, that the rays comprised between the red at one end, and the violet at the other end, of the spectrum, are *dispersed* or separated farther from each other, by the oil of cassia, than by the glass prism.

95. But this is not the only point of difference between different spectra. If we compare two spectra of precisely the same length, but cast by different substances,—we shall find that the relative distribution of colour is not alike. Thus, if we take a prism of oil of cassia, and another of sulphuric acid,—such that they afford spectra of the same length, (and this can be effected by varying the refracting angle or apex of the prisms), we shall find that the centre of the spectrum in one does not fall upon the same colour as the centre of the spectrum in the other; it will fall among the *green* rays in the sulphuric acid prism, and among the *blue* rays in that of oil of cassia. This variation is occasioned by a difference in the degree to which the rays are dispersed on either side of the central ray: thus, with sulphuric acid, the less refrangible rays, such as red, orange, and yellow, will be more dispersed than with oil of cassia, while in the latter, the more refrangible rays, such as blue and indigo, will be more dispersed than with the sulphuric acid; and thus the centre of the spectrum will be brought among the *blue*,

instead of among the green rays. The violet rays are totally absorbed by the oil of cassia; so that a prism of this medium is without this end of the spectrum.

96. This property of different prisms, renders it impossible for us to determine with accuracy the *real* proportion between the several colours of the spectrum. Sir Isaac Newton endeavoured to measure the ratio between them, as given by the prism which he employed; but, had he extended his researches to other bodies, he would have found that such proportions by no means existed in all. The result of Newton's measurements must, then, be considered as vague and uncertain; since it depended only on the judgment of the eye to say how far one colour should extend, and where another should begin. It was also difficult, and even impossible, to measure the differences in the effects of prisms formed of different substances, until the discovery of the fixed lines furnished a certain and efficacious method.

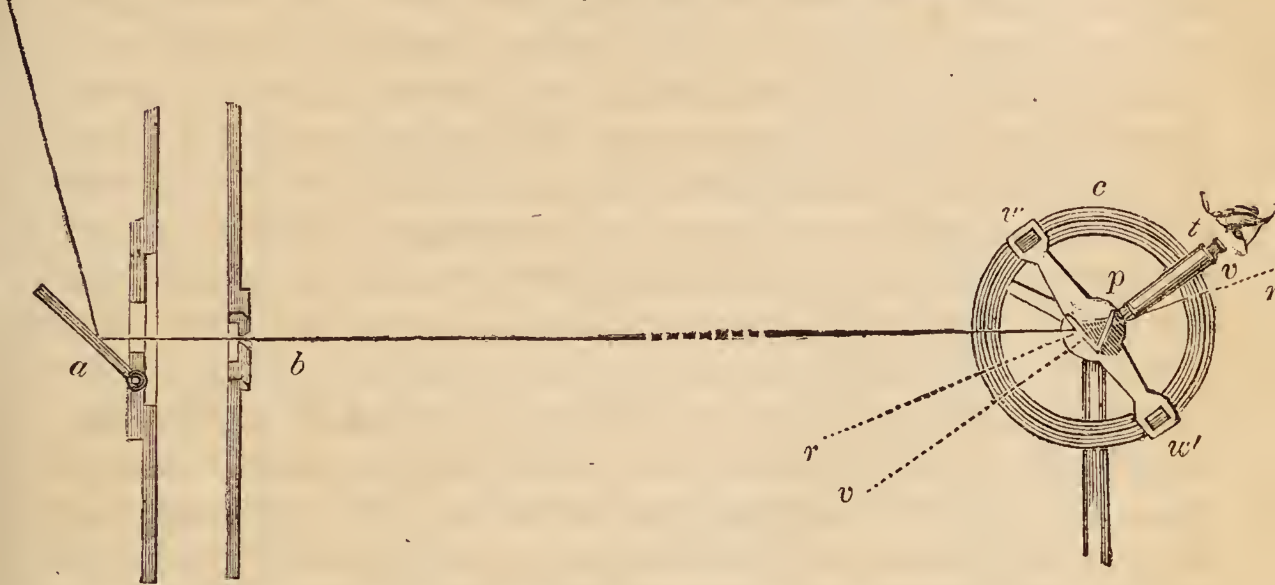
This method was first contrived and practised by Fraunhofer, who made use of the dark lines as a basis of exact measurement of refracted indices. This he accomplished by measuring the relative distances of the lines B C D, &c., from each other, in the colours of the various spectra formed by different substances; and, as those lines were the types, or representatives, of the colours in which they occurred, an increase of distance between any two lines (occasioned by an increase of the difference of the refractive power,) is indicative of a greater dispersive power possessed by the prism, with respect to the rays included between those two lines.

Fraunhofer accordingly observed, by means of an extremely delicate apparatus, the deviations of these precise and well-defined parts of every spectrum, and thence deduced the refractive index for each of the seven standard rays. He did this for ten substances, of which he formed prisms; viz., four kinds of flint-glass, three of crown-glass, one of water, another from a solution of potash, of the specific gravity 1·416, and one from oil of turpentine, specific gravity 0·885.

97. The nature of the apparatus used in these determinations will be understood by reference to fig. 19. For viewing the extreme rays of the spectrum, the sun's light is necessary; the light of the clouds is sufficient for the other rays. For throwing the sun's light into a room, an inclined plane mirror is employed as at *a*. The rays pass through a narrow slit *b*, and at some distance off fall on the hollow prism *p*, filled with the medium to be examined. The spectrum *r v*, is viewed by means

of a telescope t, which has cross-wires in its focus, and moves on an arm about the centre of the graduated circle c, where the prism is so placed as to be easily adjusted to parallelism with the slit, and the position of minimum deviation. The indications which measure the angle of deviation, for any given ray, from the direction in which it falls when no prism is interposed, are read off by verniers at w w'.

Fig. 19.



98 Fraunhofer and Wollaston remarked, that the appearances of the dark lines in the spectrum varied with the nature of the light employed to form it. The light from the flame of a candle, received through a narrow slit, and examined by a prism of flint-glass, gives only one line, and that is a *bright* one, which corresponds to the line D in the solar spectrum. From a spectrum formed by the base or blue part of the flame, the appearance is that of several coloured bands, with intervals dark and wide. Fraunhofer found the light of the moon, and of Venus, to give the *same* lines as *solar* light. The brightest fixed stars produced lines *peculiar to themselves*. Electric light was found to have a number of bright lines of a very peculiar kind.

99. Professor Wheatstone has recently examined the spectra obtained from electric and voltaic lights, by means of a flint-glass prism viewed through a small telcscope. He has found, that the bright lines vary in number and position, according to the nature of the metals from which the sparks are taken, and when the spark was produced between two dissimilar metals, the lines belonging to both are seen simultaneously. When electro-magnetic light was employed, the spectrum presented this peculiarity :—instead of a continuous succession of tints or coloured

spaces, interrupted only by faint dark bands, (seen in the ordinary spectrum) it was completely broken up by broad dark spaces, so that it was, in fact, reduced merely to a certain number of isolated narrow bands of light of different colours, and at wide distances from each other. When the spark was taken from mercury, seven bright bands were seen, none of which corresponded to the red end of the spectrum, the first or lowest being orange, and double; then green; next blueish-green, double; then purple and violet. The spark taken from zinc, cadmium, tin, bismuth, and lead in a melted state, afforded similar results; but the number, position, and of course, colour, of the lines, varied in each case. The appearances were found so distinctly marked, that this method affords means of detecting at once, the presence of any particular metal. The spectra of zinc and cadmium were marked by the presence of a red line, which is wanting in all the others.

The voltaic spark from mercury was taken successively in the vacuum of an air-pump, in the more perfect Torricellian vacuum, in carbonic acid gas, &c.; and the same results were obtained as when the experiment was performed in air, or in oxygen gas. Hence an important inference resulted; viz., that the spark and the modifications in the nature of its light, were not due to combustion of the metal. By way of further elucidation of this point, Professor Wheatstone examined, by the prism, the light accompanying the ordinary combustion of the metals in oxygen, and by other means, and found the appearances altogether dissimilar from those above. He concluded, therefore, that the sparks cannot result from the combustion of the metals employed in the voltaic combination; but rather from a portion of the metallic conductor, which is carried off by the electric discharge, and ignited.

100. No satisfactory explanation of the dark lines in the solar spectrum has yet been given. It is supposed that they are absolute interruptions in the continuity of the spectrum; or the vacant spaces left by certain definite rays absolutely deficient in the solar light. It has been lately discovered by Sir David Brewster that nitrous acid gas*, by its peculiar absorption when

* Sir D. Brewster examined by means of a fine prism of rock-salt, with the largest possible refracting angle (78°), the light of a lamp transmitted through a small thickness of nitrous acid vapour; and observed the spectrum to be crossed with hundreds of lines or bands, far more distinct than those of the solar spectrum. The lines were sharpest and darkest in the violet and blue spaces, fainter in the green, and extremely faint in the yellow and red spaces. When the thickness of the gas was

the light is transmitted through it before reaching the prism, produces the dark lines with wonderful distinctness. He has shown that the dark lines, thus produced, are invariably no more than enlargements of lines previously existing in the simple spectrum; though the changes, thus made in its appearance, are so great, as for a time to mislead the judgment, by exciting the idea that an entirely new set of lines is formed.

101. Such, then, is an account of the dark lines in the spectrum. We have considered the subject somewhat at length on account of its importance, and the influence it is likely to exert on future determinations of the optician, since they will enable him, as Sir J. Herschel remarks, "to give a precision, hitherto unheard of, to optical measurements, and to place the determination of the refractive powers of media on the several rays, almost on the same footing, with respect to exactness, with astronomical observations." We now proceed to say a few words respecting the *distribution* of light in the spectrum.

102. The delicate manner in which Fraunhofer performed his experiments, enabled him to determine at what part of the spectrum the intensity of the light was greatest; and he found that, instead of being in the centre, it was much nearer to the red end of the spectrum. If we divide the length of the spectrum into five equal parts, the point of greatest illumination will be at the distance of one of those divisions from the red end, and consequently at a distance of four from the violet end. He likewise found that, if the intensity of the light at that point be called 1, the intensity at the several points B C D, &c., (fig. 18), was as follows:—B. 0·032, C. 0·094, D. 0·064, E. 0·48, F. 0·17, G. 0·031, H. 0·0056.

103. We have been occupied thus far in examining the principal set of rays in the constitution of the prismatic spec-

increased, the lines became still more distinct in the yellow and red spaces, and broader in the blue and violet, a general absorption advancing from the violet extremity, while a specific absorption was advancing on each of the fixed lines in the spectrum. As Sir David could not obtain a sufficient thickness of gas, to develope the lines at the red extremity, he tried the effect of heat upon the vapour, which was confined in close tubes; and ascertained the extraordinary fact that this vapour, at first of a pale straw yellow, became, by heat alone, and without decomposition, as red as blood; and on augmenting the temperature it became so absolutely black, "that not a ray of the brightest summer's sun was capable of penetrating it." It was found that heat produced the same absorptive power as increase of thickness: by heating, therefore, a tube containing a thickness of half an inch of the vapour, every line and band in the red rays were made distinctly visible.

trum; viz., the *colorific*. Besides these, there are other rays,—the *calorific*, or *heating* rays; and the *chemical* rays. These we shall examine in order.

It was long supposed that the heating power of the spectrum was in proportion to the quantity of light existing at any particular part of it; and hence *yellow* was said to be the warmest of the colours of the spectrum. But Sir William Herschel, being engaged in telescopic observations on the sun, found that the coloured glasses, which he employed to diminish the light, became so warm, by absorption of heat, as frequently to break. This led him to examine the calorific power of the several rays, and in doing so he considerably extended the analysis of light, as originated by Newton.

104. Herschel formed the spectrum in the usual manner, by means of a glass prism, and received it upon a screen of pasteboard, in which a narrow slit was made, sufficient to allow only one of the colours to pass through, which fell upon the bulb of a very delicate thermometer, placed behind. He began with the violet, and so allowed each set of rays to fall on the thermometer-bulb. The heating effect was found to increase from the violet to the red. In the latter ray, it was found to be four times greater than in the former. Hence it appeared that the most brilliant part of the spectrum was *not* the hottest. During this investigation, it happened that the screen was moved so far in one direction that the space beyond the red ray, in which no light whatever was visible, coincided with the thermometer, whose temperature was immediately observed to rise; indicating the presence of invisible, but calorific rays, exerting a greater heating action than those of the red rays; the maximum effect being attained a little below the boundary of light. These rays are refracted by the prism in the same manner as the colorific rays; but the amount of refraction is smaller. The various temperatures in the different colours, as stated by Sir H. Englefield, are as follow: viz. In the blue 56°, in the yellow 62°, in the red 72°, and beyond the red 79°. At $1\frac{1}{2}$ inch beyond the red, the heat was considerable.

105. These experiments were soon repeated by various philosophers, and verified by some; while they were questioned by others. Berard employed a *heliostat**, an instrument constructed for the purpose of reflecting the *solar* rays *constantly in one direction*, notwithstanding the change of position of that

* This word is from the Greek, ἡλιος, *the sun*, and στατος, *standing still.*

luminary. By these means a spectrum was obtained, which was steady and immoveable for any length of time during the day. Berard verified the experiments of the English astronomer, with this single exception:—he found the maximum calorific effect to terminate exactly at the extremity of the luminous spectrum, where the thermometer-bulb was quite covered with red light. This difference probably arose from the different nature of the materials of the prisms employed by the two observers; since it has been found by Seebeck that the position of greatest calorific intensity varies with the nature of the prism employed. With a hollow prism filled with water or alcohol, the greatest heat was in the yellow rays. With sulphuric acid, or corrosive sublimate, it was in the orange rays: with a prism of crown-glass, it was within the red rays: but with one of flint-glass, it was, as Herschel stated, beyond the red rays.

106. It is interesting to remark that the invisible calorific rays are subject to all the laws which regulate the luminous rays: they can be reflected, refracted, focalized, and even polarized. We pass on now to consider another set of rays, viz., the *Chemical.*

107. The chemical rays are invisible, and do not possess any appreciable heating power; but from the energy which they exert in decomposing certain compounds, and producing others, they have received the appropriate name of *Chemical* rays. Scheele first noticed that the white chloride of silver is rendered *blacker* by the violet, than by the other rays of the spectrum. Ritter, in 1801, while repeating Herschel's experiments, found that the same salt soon became black beyond the violet end of the spectrum. He also found that phosphorus emitted white fumes of phosphorous acid, in the invisible red or calorific rays; but beyond the violet end the fumes ceased. Seebeck found the colour of the chloride of silver to vary with the coloured space in which it was placed. In and beyond the violet it was reddish-brown; in the blue it was blue or blueish-gray; in the yellow it was white or faintly tinged with yellow; and in and beyond the red it was red. The salt was decidedly coloured beyond the limits of the spectrum, when a prism of flint-glass was employed.

Dr. Wollaston obtained the same results independantly of Ritter. He also discovered some effects of light upon gum guaiacum. He dissolved it in alcohol, and spread some of the tincture on a card. The colours of the spectrum had no effect upon it until concentrated by a lens. Then, in the violet and blue rays its colour became green: in the yellow rays no effect was

observed: in the red rays the card, which had been made green in the former case, had its original colour restored.

108. The chemical rays are more refrangible than any of the other rays of the speculum: they extend beyond the violet, and terminate probably in the green light.

109. Many phenomena in nature, in science, and in the arts, are supposed by good reasoning to be due to the effects of the chemical rays, or, perhaps we may say, the chemical properties, of light. Light seems almost as necessary to the well-being of animals and vegetables as atmospheric air. Animals confined in the dark become pallid, thin, and spiritless. Many plants will not grow in the dark; and those that do, are generally white and often noxious as articles of food. The writer once planted a potato in a dark cellar, and made a small hole in one side of the cellar, through which light faintly gleamed. The shoots of the potato directed themselves towards this aperture, and one shoot, which was nine feet in length along the ground, and four feet in addition up the wall, succeeded in gaining the aperture, and thrusting its extremity through it into the light. At this end only was any colour perceptible, which was a pale green: the shoot itself was quite white.

It is for the purpose of protecting the internal parts of some vegetables from the action of light, that gardeners "tie up" lettuces, &c.; and with the same view, celery is cultivated as an article of food, by heaping up the soil upon its stem, so as to screen it from light: without this precaution celery soon alters its aspect; it throws out shoots and leaves, and, instead of remaining white and of a mild agreeable taste, it becomes dark green, and acquires a very bitter nauseous flavour, and is held to be poisonous. The heart of the endive is bitter and tough, and not fit for food, unless it has been sheltered from the light.

110. The colorific rays of the spectrum impart colour, and the calorific and chemical rays increase the vigour of organic creations. Thus we find life, both animal and vegetable, to be richer and more prolific in warmer climes, where vegetables possess, in an exalted degree, all those properties which strike the senses,—gay colours, pungency of taste and odour,—from

> Groves whose rich trees weep odorous gums and balm,

or where

> . . . . north-east winds blow
> Sabean odours from the spicy shore
> Of Araby the blest.

We find that the soil in forests generally consists of a black rich earth, destitute of vegetation. The trees shoot up to a

great height, in order to present their leaves to the light, and the trunks possess scarcely any foliage. In the American woods the side of the tree exposed to the sun is of a darker hue than any other part of the trunk. The savage is said to guide himself by this mark, which he knows to be the south side, in his journeys through the wilds.

111. The two gases, hydrogen and chlorine, if mingled in the dark or by artificial light, exert no action upon each other; but, if the mixture be exposed to the light of day, they combine with an explosion and form muriatic acid. The combination is effected with great rapidity in the direct rays of the sun. Professor Brande found that the light obtained from charcoal-points, ignited by a galvanic battery, also effected the combination. The writer has exposed the mixture to the powerful oxy-hydrogen light; but the combination was not effected by its means, although that peculiar cloudiness appeared, which precedes the explosion of the gases, when exposed to natural light.

Phosgene gas, which is a compound of chlorine and carbonic oxide, can be formed in no other way, as far as we know, than by exposing a mixture of the two gases to the light of day.

The marking of linen is frequently effected thus:—the linen is wetted with a solution of carbonate of soda, and when dry the letters are written with a solution of nitrate of silver. A double decomposition ensues, by which nitrate of soda and carbonate of silver are formed; and light expelling the carbonic acid from the latter, the black oxide of silver remains on the cloth, whence it cannot be removed by any means, except perhaps by *liquor ammoniæ.*

112. We have already stated in our article on the Thermometer, (108,) that M. Melloni succeeded in depriving the solar rays of the heating part of them, so as to preserve the light, even in a concentrated state, entirely devoid of heat. Our distinguished countrywoman, Mrs. Somerville, has succeeded in isolating the chemical rays. This she effected by means of very pale thin green glass, behind which was placed some pure white chloride of silver, spread evenly upon paper. An exposure of it for half an hour to the direct rays of a hot sun, produced no change in the chloride. Different kinds of green glass were found to be nearly all impermeable to the chemical rays; as also plates of deep green mica; whereas six superposed plates of ordinary white mica allowed the chemical rays to pass.

It is singular that the chemical rays passed easily through a very fine green emerald: a deep red glass scarcely allowed them to pass; while a garnet, equally red, transmitted them readily.

Rock-salt, white, blue, and violet glass, presented the maximum of permeability; green glass and green mica the minimum.

Hesler has found that, when a paper was moistened with a solution of gum, sprinkled with chloride of silver, and exposed in a direct manner to the solar spectrum, the darkening effect varied with the nature of the prism employed. It was nearly instantaneous with a prism of water or spirits of wine: it occurred in the course of twelve or thirteen minutes with the oils of turpentine and cassia; in two minutes and three seconds with flint-glass; in one minute and five seconds with crown-glass. The maximum chemical effect with spirits of wine was obtained in the violet, near the blue; with water in the violet; with oil of cassia, nearly two inches outside the violet.

113. Many solutions refuse to crystallize if placed in the dark; but do so readily when light is admitted to them, and form in greatest abundance at the side of the vessel most exposed to the light. In the bottles containing camphor in apothecaries' windows a beautiful crystalline deposit of that substance may be seen on the side of the bottle most exposed to the light. If camphor be placed in the exhausted receiver of an air-pump, and the receiver be placed in the sunshine, small crystalline specks will appear in a few minutes on the side nearest the sun, which continually increase in size, and in two hours many beautiful stellated crystals, from one-eighth to half an inch in diameter, will be found on the exposed side of the glass. Sometimes the whole side next the sun is covered with a lamina of camphor, the other side containing none.

Nitric acid, when exposed to the sun, loses oxygen, and is converted into an orange-red liquid, similar to nitrous acid. Oil, similarly exposed, loses its yellow colour; but resumes it, if again allowed to remain in the dark.

114. It is a usual practice to place a screen before a fire, which is burning languidly, or to close the window-shutters, in order to prevent as much as possible the access of light to the burning materials; from an opinion that the solar rays, or even the ordinary light of day, (to use a popular expression) "puts the fire out." Experiment proves that this practice is *not* one of the "vulgar errors," as we shall now proceed to show.

Dr. M'Keever took two portions of green-wax taper, each weighing ten grains, and ignited both at the same moment. One piece was placed in a dark room, and the other was exposed to broad sunshine: thermometer *in the sun*, 78° Fahr.:—*in the room*, 67°.

In 5 minutes, $\begin{cases}\text{the taper in sunshine lost . . } 8\frac{1}{2} \text{ grains.}\\ \text{the taper in darkened room lost } 9\frac{1}{4} \text{ grains.}\end{cases}$

When one taper was placed in full moon-light, and another in the dark, the loss was equal in both cases.

A piece of green taper, accurately divided into inches, was set in a darkened room, and the coloured rays of the solar spectrum were cast upon it in succession, with the following results:

	To consume 2 inches of taper.	
In the red ray it took	8′	0″
In the green ray . . .	8	20
In the violet ray	8	39
At the verge of violet ray . .	8	57

Commencing with the violet ray, the loss was as follows:—

	To consume 1 inch.	
At the verge of the violet ray it took .	4′	36″
In the centre of violet ray . . .	4	26
In the centre of green ray . .	4	20
In the centre of red ray . . .	4	16

It appears, then, that the solar rays, in proportion to their intensity, are possessed of the power of retarding, to a considerable extent, the process of combustion; and, that this phenomenon is occasioned by the action of the chemical rays on the portion of atmospheric air that immediately envelopes a particle of matter about to undergo combustion, aided probably by the high temperature of the portion of materials that have already commenced this process.

115. In the art of dying, it is known that many tints can be obtained only by exposure to light. It is related that an English dyer, wishing to produce a delicate tint, communicated to silk in France, went over to that country, and offered a large sum of money to a French dyer to be made acquainted with the process. This was accepted, and the French *artiste* showed him every step of the process, and ended in the production of the required tint; but the Englishman was mortified to find that he himself had previously gone over the very same process, and had obtained only an obscure muddy dye. While he was venting his chagrin at having paid a large sum of money to be made acquainted with what he already knew, the Frenchman told him to remark that the day was one of bright sunshine, and on such days only did he practise the method just explained to the Englishman; for, he observed, *on cloudy days* the process would fail. Our countryman, whose trials had been made within a factory, where the sun never

shone, now removed into the country, and performed the process with success.

Réaumur, the French chemist, also, re-discovered the ancient Tyrian purple dye. He had gathered some shells on the coast of Poitou, and crushing them by chance in his hand, his shirt-sleeve became wetted with the moisture which exuded. An hour after, he observed his sleeve to be of a bright purple colour, which was durable. He gathered other shells of the same kind, and crushed them upon linen; but, as they did not give out the colour at once, he feared his discovery had been lost again almost as soon as made; but, the linen, having been left exposed to the light for some time, assumed the bright purple colour so much desired.

116. Such, then, is a brief account of the effects of the chemical rays of the solar spectrum. Wonderful and mysterious as their action is, as already described, it is certain that we are as yet but imperfectly acquainted with the various effects and phenomena of light. There is still enough left undiscovered "to exhaust the labours of philosophers," as Sir D. Brewster remarks, "for centuries to come;" so that we have no grounds for being vain of our knowledge, since we are, in this science, only just embarked upon the "great ocean of Truth," whose horizon is near at hand,—whose limits are far beyond our narrow gaze: while in the land that we are leaving, or have just left, much of our best philosophy is,

> Held in the magic chain of words and forms,
> And definitions void.

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117. It appears then that the *solar* spectrum is formed of three distinct spectra; namely, the *luminous*, or *colorific* spectrum; the *heating*, or *calorific* spectrum; and the *chemical* spectrum. All three are, to a certain extent, superposed on each other; but the chemical extends beyond the luminous spectrum at the upper end, and the calorific spectrum beyond the luminous at the lower end. Each set of rays is variously refracted by the prism, the chemical rays being refracted most, and the calorific rays least. In this respect, however, much depends upon the *nature of the material* of which the prism is formed.

The violet rays of the spectrum possess a peculiar *magnetising* property, which we notice in our article on the Compass (43).

We pass on now to consider some of the direct effects, in nature, of the decomposition of light.

Section III. The Rainbow, &c.

118. We are now about to apply the doctrine of the decomposition of light, to the explanation of one of the most beautiful phenomena of Nature: viz., the *Rainbow.*

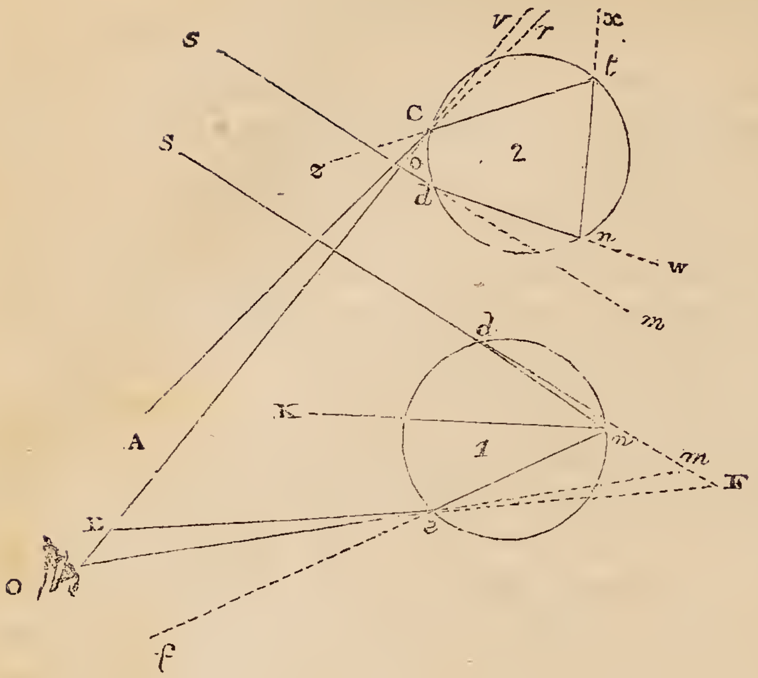
> Refracted from yon eastern cloud.
> Bestriding earth, the grand ethereal bow
> Shoots up immense; and every hue unfolds,
> In fair proportion running from the red,
> To where the violet fades into the sky.

119. It was utterly impossible to give a correct theory of the rainbow, until it was discovered that light consisted of different colours, susceptible of separation in passing through a refracting medium: but, when this property of light became known, the origin of the rainbow became a problem, which admitted of very exact solution. The questions, then, to solve are, "Why does the rainbow appear as a segment of a circle?" and "why is it composed of several curves or bands of coloured light, one melting into the other, and presenting a graduated scale of tints from its concave to its convex edge?" and in the third place, "why do two bows, an inner and an outer one, generally appear?"

120. Suppose that an observer is placed at the point O, fig. 21, with his back to the sun, and that at some distance in front of him, rain is falling; the air between the sun and the drops of rain being sufficiently clear to allow the sun's rays to illuminate them, while falling to the earth. Under such circumstances the observer often witnesses two *arcs* or *bows* immediately in front of him, these arcs being portions, more or less extensive, of circles. When two bows are seen, the colours of the inner bow are more striking and vivid than those of the outer bow. Each exhibits the same series of colours as in the spectrum formed by the prism: viz., *red*, *orange*, *yellow*, *green*, *blue*, *indigo*, and *violet;* but *red* is the uppermost colour in the inner bow, and *violet* in the outer bow. The production of both bows depends upon the *refraction of light*, as also upon its *reflexion;* and they are never seen, except when the incident rays form with the emergent rays a certain angle, which we are now about to explain.

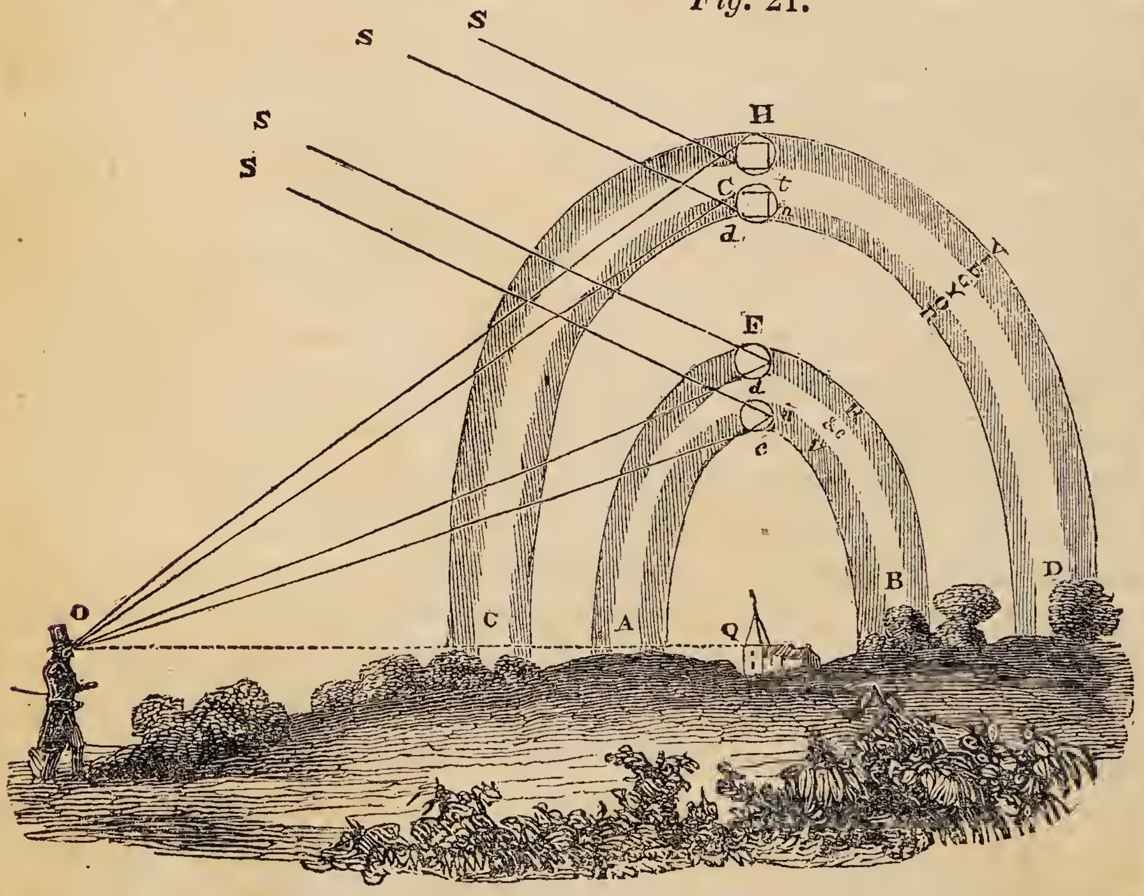
121. Suppose that, at the upper part of the inner bow, A F B, (fig. 21,) there are drops of rain in the act of falling, and that rays of the sun's light, S F, S *d*, fall upon that surface of the drops which is nearest the sun. If the point, F or *d*, were directly in the right line joining the middle of the sun and the

Fig. 20.



middle of the drop, the rays would pass through, and form a focus on the other side, as we have already explained in the case of a glass sphere, (46); but the point, F or *d*, in these drops is out of the central line, as may be seen, and is on the upper side of it. When, therefore, the ray impinges on the convex surface at *d*, in the *first* circle of fig. 20, (which circle is a magnified representation of one of those at the upper part of the inner arch,) a small portion of this ray is reflected at *d*, but the larger portion

Fig. 21.



enters the drop; and, instead of continuing its course to *m*, is refracted according to the laws of refraction, and is bent towards *n*. At the point *n*, a further separation of the ray takes place;

some portion of it passing through the hinder surface of the drop, while another portion is reflected from the internal surface at *n;* (for we have seen, by reference to a looking-glass, (14,) that rays may be reflected both from the outer surface and from the surface of the mercurial amalgam behind; and we may here state generally, that, whenever a change of medium occurs, a portion of the rays is reflected at the boundary between the two media; such as glass and mercury, glass and water, water and air, &c). Those rays, which are reflected from the point *n*, at an angle, K *n e*, equal to the angle of incidence, K *n d*, approach again towards the anterior surface, which they reach at the point *e;* penetrating through which they finally emerge from the drop, and, instead of going on towards *f*, are refracted again, and reach the eye of the observer at O.

122. It will be thus seen that the light, which enters the drop, is once reflected, and twice refracted, before it reaches the eye at O; and, moreover, that the quantity of light undergoes three successive stages of diminution, from the time of its first reaching the drop to the time that it finally emerges from it:—1st, there is a portion of light reflected at *d;* 2nd, there is a portion which passes out of the drop at *n;* and 3rd, there is another portion which is lost by reflexion from the drop at *e;* so that the quantity of light, which actually reaches the eye at O, is comparatively small.

123. But we have hitherto spoken, as if the rays of light were undecomposed in the course of these refractions and reflexions. We must now, however, take the *chromatic* composition of light into account, and see what follows from it. When a ray of light falls upon a drop of rain, it is, on penetrating the surface, refracted into another direction; but that direction is only a general representation of the path of the rays. The violet rays will be more refracted from their original path than the red rays, as we have shown (59 *et seq.*,) in the case of the prism; so that, by this difference of refractive power, the point *n* should be lower down in the drop with respect to the violet rays, than with respect to the red rays;—the rays being decomposed, when they arrive at *n*. Now, if we suppose, for a moment, that there are *two* points at *n*, (which would be too close for us to give separately in the figure), we shall see that they must approach the hinder surface at different angles of incidence: and as the violet and red rays are reflected at angles respectively equal to their angles of incidence, it follows that the point *e* becomes spread out with rays of different colours; the violet being on the right of the red, or nearer than the red to the sun. Instead,

therefore, of one homogeneous, or one white ray emerging at the point *e*, there are two rays, one *red* and one *violet*, at a short distance apart from each other;—the interval between them being occupied by all the intermediate tints, *orange*, *yellow*, *green*, *blue*, and *indigo*. It follows, therefore, that, as those different rays leave the drop at different points, they cannot all reach the eye of the observer at O: but, if some do so, others cannot. Now, to determine which of the coloured rays will pass out of the drop in such a direction as to reach the eye at O, we must know what is the angle formed by the solar ray with the ray proceeding from the drop to the eye at O; or, in other words, we must determine the angle S *m* O. The refraction of light at the drop being regulated by fixed laws, which admit of mathematical computation, we discover that if the solar ray S *d*, carried straight on to *m*, make with the ray O *e*, likewise produced to *m*, an angle of 42° 2′, the ray from *e* to O will be *red*. Again, supposing the eye to be raised to B, and the ray B *e*, produced to F, to make with the solar ray S F an angle of 40° 17′, the ray from *e* to the eye at B would be *violet:* for it is evident from inspection that, in this case, the smaller the angle, the greater will have been the refraction of the ray in meeting the eye. It is evident also that, as, in this case, the violet ray makes the smallest angle of any with the solar ray, the violet must tend more to the *horizontal*, and so be seen *lowest* down of any of the rays of the rainbow; and that all the other tints of the spectrum will take their proper places from the *violet* upwards to the *red*. All the tints of the spectrum result from each and every drop; but we see only those, whose angle we are in one of the lines of. Hence, it follows that, as the red ray makes with the solar ray an angle of 42° 2′, and as the violet ray makes with the solar ray an angle of 40° 17′, the red ray makes with the violet ray an angle of 1° 45′; which we find would be the breadth of the interior bow, if the sun were only a *point:* but, as the mean diameter of the sun is about 32′, this quantity must be added to the already resulting breadth: so that 1° 45′ + 32′ = 2° 17′, the apparent breadth of the bow, as thrown upon the celestial sphere.

124. The inner edge of the principal rainbow is, as we said, *violet*, and the outer edge *red*, owing to the greater refrangibility of the violet rays. Consequently, the violet rays of the drops, which are at the outer edge of the bow, pass away over the head of the observer, and do not enter his eye; while the violet rays of the drops at the inner edge, are refracted exactly in the proper direction to enter the eye. Applying a similar course of

reasoning to the red rays, we find that these, not being turned in the first instance so much out of their original path, must be at a greater distance from the centre of the arch, in order to enter the eye: so that the red rays of those drops which form the inner edge of the arch, are refracted to a point on the surface of the earth away off in front of the observer, and therefore do not enter his eye; but the distance of the drops forming the outer edge of the bow, from the centre of the arch, is such as to transmit the red rays directly to the observer's eye. This reasoning applies to the upper parts of the bow, as well as to the parts, which bend downwards to the earth; because the angle is constant for each of the rays respectively, whether the drop be at the summit of the arch, or at a point nearer to the earth. If a right line were drawn from the centre of the sun, through the eye, to the opposite part of the sky, the point of the sky reached by this line would be the *centre* of the rainbow; and, were it possible for us to be elevated to such a height above the surface of the earth, that no obstruction should exist to our view, we should see the rainbow as a *perfect circle*, the centre of which would be the extremity of the line drawn through the sun and the eye, and produced till it met the circle.

125. We have been describing hitherto the production of a rainbow, such as is generally seen; but there is sometimes seen another rainbow, exterior to this, whose colours are much fainter;—indeed, so much so, that it often escapes notice altogether. This is usually called the *secondary* rainbow (the other being the *primary*); and we will now proceed to explain its formation.

126. When we consider that the innumerable rays from the sun impinge upon the anterior surface of a drop of water at different angles, it must be manifest that these rays are variously affected by the reflecting and refracting powers of the liquid globule. In the preceding instance we traced the progress of a single ray, which, after one reflexion and two refractions, emerged from the anterior surface of the drop at an angle corresponding to its colour. We must now trace the progress of another ray, which helps to form the exterior bow C H D. In the case of the interior bow, the solar rays impinge upon the *upper* surface of the drop; but in the exterior bow, the rays impinge upon the *lower* surface of the drop. The circumstance of either of these impingements, together with the angle of refraction, determines the *fact* and *character* of the bow.

127. A ray S *d* impinges on the surface of the lower half of the drop, at *d* (fig. 20, circle 2), and, instead of proceeding to *m*,

is refracted to the point *n*. At this point a portion of the light is transmitted on to *w*, and the remainder is reflected upwards within the drop to the point *t*. Here again a further portion of light is transmitted on to *x*; and the remainder is again reflected, at an angle equal to the angle at *n*, to the point *c*. A portion of this also is carried on by reflexion to *z*; and the final remainder, which is now but a small fraction of the original beam, is, after another refraction, transmitted in such a direction as to enter the eye at o.

128. In the case of the *primary* or *interior* bow, we adverted to *one* reflexion and two refractions of the ray of light incident on the drop; but, in the case of the *exterior* or *secondary* bow, we have to notice *two* reflexions and two refractions of the incident ray: consequently, the loss of light occasioned by this additional reflexion accounts for the dimness of the light, shed by the secondary rainbow.

129. We have thus far considered the exterior bow, as if the light were undecomposed, or white light; but we have now to observe that the red and violet rays, which such white light contains, will be still further separated here, than in the primary rainbow; because the angle, by which these rays reach the eye, is, for either ray, larger than in the case of the primary rainbow, owing to the greater diameter of the outer bow. The red and violet rays cannot both fall precisely at the points *n t* and c; but if *d n* be the path of the red ray, the violet will be somewhat in advance, owing to its greater refrangibility. If, therefore, a drop be in such a position as to send the violet ray to the eye, the red ray of this drop will be directed over the head of the observer, and will not enter the eye. But, if the drop be in such a position as to send the red ray to the eye, the violet ray from the same drop will fall short of the spectator. So that, in order that two drops should send, the one a red ray, and the other a violet ray, to the eye at o, at the same instant, the drop that sends the violet ray must be more elevated than the drop that sends the red ray, in the case of the secondary rainbow;—whereas we have seen that, in the *primary* bow, the reverse is the case. The red ray, on emerging from the drop in the exterior bow, makes with the sun and the eye an angle S *o* A of 50° 57′, and the violet ray an angle S *o* B of 54° 7′. The size of the angle made by the violet with the solar ray is greater in this case, for the same reason that it was less in the former. Hence, by the reasoning in the former case, the breadth of the secondary bow must be about 3° 42′; and the distance between the bows, or the space between the red of the outer, and the red of the

inner, bow, must be $50° 57' - 42° 2' = 8° 55'$, which, diminished by the solar diameter, gives $8° 23'$ as the space between the bows.

130. If we could see the whole of the concentric bows in the perfect form as circles, we should find that the diameter of the inner bow from violet to violet would be nearly 81°; and that the diameter of the outer bow from red to red, would be nearly 102°. The bows may be seen as complete circles, if the observer be on an eminence, and the sun near the horizon, or just at or below it; and if the rain-clouds be over a valley at no great distance from him. How the angles made by the coloured ray with the sun and the eye become greater, in proportion as they recede from the centre of the bow; and how the breadths and diameters of the bows may be estimated, the student may learn from a careful attention to the principle of the 16th Prop. of the 1st book of Euclid.

131. A greater or less segment of the rainbow is visible, on level ground, according to the elevation of the sun above the horizon. When the sun is in the horizon, the visual axis, (which answers to the axis of the cone of rays proceeding from Q to the eye of the observer at O, fig. 21), coincides with the horizon; and the form of the rainbow is then semicircular. In proportion as the altitude of the sun is increased, the visual axis sinks below the horizon, and the bow becomes diminished. When the sun's altitude is 42° 18′ (the semi-diameter of the interior bow from the centre to the red), the interior bow will not be visible above the horizon; the summit of the secondary bow still having an elevation of rather more than 12°. So that, if the sun be higher than 54° 23′ (the semi-diameter of the exterior bow from the centre to the violet), the exterior bow likewise will have fallen beneath the horizon.

132. Thus we have described the formation of the primary and secondary rainbows. The ordinal number of rainbows is, however, not necessarily limited to *two;* for the incident rays may impinge upon the drop in such wise as to produce *three* reflexions within the drop, and thus form a *tertiary* rainbow; but the colours of this third bow are so much weakened by the loss of light sustained by three reflexions, that this bow is seldom seen, unless the sky be very dark overhead, and the sun be shining strongly. Another reason why the tertiary bow is seldom, if ever seen, is that is it not looked for, or expected, and therefore is most likely, if present, to remain unseen. We may even suppose the incident rays to undergo *four* reflexions within the drop, and so form a *quaternary* rainbow; but this fourth bow has never been seen except by the eye of theory.

Other bows are also sometimes seen below the primary bow; but in these, only one or two of the colours are visible.

133. Thus have we traced the production of the rainbow, to the operation of the simple laws of refraction and reflexion, observed by these "natural prisms," the falling drops of rain, with regard to the rays of light which pass through them. There can scarcely be found a more wonderful illustration of the velocity with which light moves, than is afforded by the production of the rainbow. If any appreciable time were employed by the light to perform the circuit of the drop, the latter would have moved from its position, and the results now experienced could not take place; but, as it is, the light enters the surface of the drop, undergoes within it one or two reflexions, two refractions, and decomposition; and has reached the eye; all in a portion of time too small for the drop to have fallen down through a space which can by any test be detected.

134. We need scarcely remark that no two observers see the *same* rainbow; that is to say, the bow produced by one set of drops to the eye of one observer, is produced by another set of drops to the eye of another observer, whose angular difference of position is ever so small. It is not necessary that a cloud should be behind the rainbow, although we usually see one on account of the prevalence of rain. We have more than once seen the bow with the blue ground of a cloudless sky behind it. A portion of a bow, more or less than a quadrant, is very often seen in showery weather, owing to there being no rain at the void part.

135. Moon-bows and fog-bows are occasionally seen. In the case of the *Lunar* rainbow, the moon's rays fall upon drops of rain, in the same manner as the solar rays, and are refracted and reflected by the drops; but the colours are faint, in consequence of the smaller illuminating power of the moon. In the case of *fog*-bows, the particles of moisture form the refracting media, by which the rays are decomposed. Rainbows, or rather *water*-bows, are frequently seen, when the sun shines upon a cascade of falling water, or upon a fountain. The eye of the observer must of course be in the requisite position, depending upon the angle of refraction, to observe the coloured arch. The *dew-drop* hanging from the grass in early summer's morn, when the earth is "sowed with orient pearl," frequently exhibits the prismatic colours; as also in winter, when vegetation,

> fledged with icy feathers, nods superb.

136. The manner, in which a globule of pure water extracts such splendid colours from a beam of white light, has exercised the mental powers of some of our greatest philo-

sophers;—the student, therefore, may be assured, that no natural object, however small, and apparently insignificant, is beneath the notice of a great mind; since every object in nature was created and endowed with certain properties, not only by a still greater mind, but by an Omnipotent Being, who made nothing in vain.

137. We come now to inquire into a few more of the effects of that

> . . . . Prime cheerer, Light!
> Of all material beings first, and best!
> Efflux divine! Nature's resplendent robe!

In order to understand the production of what may be called *atmospheric* colours, such as the colour of the sky, &c., it will be necessary to apply the doctrine of refraction to aërial media, such as compose our atmosphere.

We are accustomed to say, when we view an object through the air, without the intervention of any other body, such as glass, &c., that we see the object *uninterruptedly;* as if a perfect vacuum existed between the eye and the object. Such, however, is not strictly the case. If we refer to the table of refractive powers in the first section (34), we shall see that a minute refractive power is assigned to air; that is, if we had a prism of air, we should find that a ray of light in passing through it, would be slightly bent out of its path; which would not occur if a vacuum were presented to the ray. The extent of refraction is exceedingly small through a thin homógenous stratum of air; but, when we have a mass of air about fifty miles in height, increasing in *density*, from the summit downwards to the base, and consequently in *refractive power*, as it approaches the earth, we find that refraction becomes very considerable. Its amount is still more increased, if the light permeate this mass of air in a very oblique direction; because the quantity of air, to be passed through, must not only be increased by the obliquity of the ray, but its direction is through more of the denser portion.

138. Hence it follows, that, when the sun is near the horizon, his rays are considerably bent in their passage to the eye of an observer on the earth's surface; and, as this bending tends upwards, it makes the *apparent* position of the sun more elevated than his *true* position: insomuch that, when he is actually *below* the horizon, he appears distinctly visible *above* it, because the rays reach the eye by a path curving upwards. Many very remarkable consequences result from this refraction of the sun's rays, especially if, by any partial increase of temperature, the refractive power becomes more intense in one mass of air

than in another. These phenomena, however, do not belong to our present purpose, which is to explain the *colour* of the sky.

139. When the sun, or other luminous body is elevated high above the horizon, the light is transmitted to the eye with scarcely any chromatic change; but, when near the horizon, the long tract of air, through which the light has to pass, acts unequally on the different colours. The red rays, being those which are least refracted or bent out of their original path, are believed to possess a greater momentum than the violet; that is, they can force their way through obstacles more readily. A beam of white light will therefore be deprived of a portion of its blue rays, by passing horizontally through the atmosphere; the remaining colours, the red and yellow, will penetrate to the eye, and convey their impression to it. Hence, when

> Low walks the sun, and broadens by degrees,
> Just o'er the verge of day,—the shifting clouds
> Assembled gay, a richly-gorgeous train
> In all their pomp attend his setting throne.

Now, the same circumstance which makes the setting sun appear red, gives the blue tint to the sky. Those parts of the solar rays, which cannot reach the eye, become reflected from, or absorbed by, the particles of air which are at some distance from the horizon, and hence give their own colour to the air at those parts; for we find that the sky is more intensely blue near the zenith than near the horizon. That this is the cause of the blueness of the sky, is evident, from the circumstance that the higher we ascend in the atmosphere, the darker does the sky become, and the greater is the contrast between the sun and the sky. The stratum of air immediately contiguous to the earth's surface, is that which gives the blue colour to the sky; and when we ascend beyond that stratum, the air has not sufficient density to refract the blue rays to the eye. Humboldt, Saussure, and others, who have given descriptions of the phenomena witnessed from the summits of lofty mountains, speak of the intense *blackness* of the sky. This results from the fact that the air, at great elevations, is of considerable tenuity, as compared with the air at the earth's surface, and therefore cannot exert so great a refractive power as in the latter case:—the red and blue rays of the sun's light are not separated so far from one another; and thus the cause which makes the sun appear *less red*, makes the sky appear *less blue:* in short, when the mass of air is less dense than at the surface of the earth, the refractive, the reflective, and the absorptive powers are all diminished; and thus both sun and sky tend to assume those colours, which naturally belongs to them. The

sun thus appears rather as a globe of fire, immersed in impenetrable darkness; and this proves to us that one of the inestimable properties of the atmosphere is to soften the intense rays of the sun, and at the same time to diffuse a mild blue light throughout the surrounding sky; by which means the face of the earth, and every thing upon it, not enclosed on all sides, enjoys more or less, the blessing of light, even when out of the direct rays of the sun. Were it not for the refractive and reflective properties of the atmosphere, everything, not in actual sunshine, would be in blank darkness.

140. M. Saussure contrived an instrument for measuring the intensity of the blue colour of the sky. It consisted of a circular band or zone, made of thick paper or pasteboard, and divided into 51 parts, each of which was painted with a different shade of blue from the others, varying, by gradual tints, from the deepest blue (formed by a mixture of blue and black) to the lightest blue (formed by a mixture of blue and white). This coloured zone was held in the observer's hand; and the tint, which corresponded with the colour of the sky, was noted. The tints were numbered from 1 to 51, beginning at the lightest. With this instrument, which was called a *Cyanometer**, Saussure, Humboldt, and Depons have compared the blueness of the sky at different parts of the world. The general intensity in Europe is about 14; in South America, near the equator, at Caraccas 18, and at Cumana 24. These results, however, are not supposed to be indications of the actual density of the air; for it is found that, as the quantity of aqueous vapour in the atmosphere increases, the intensity of the blue colour of the sky is diminished.

141. A cyanometer has been formed by Sir D. Brewster, which consists of two plates of glass, about twelve inches long, joined together at one end, so that their surfaces may form an angle of from 12° to 20°. These plates form two sides of a prismatic vessel, which is placed upon its widest end, and filled with a blue fluid, having such an intensity that the colour near the top of the vessel, where the distance between the plates is small, is less than the minimum blue of the sky; while the intensity of the colour at the bottom of the vessel, exceeds the deepest tinge ever found in the entire convexity of the heaven. Between these two extremes there is a regular gradation of tints; and, by a proper adjustment of the angle formed by the glass plates to the intensity of the blue fluid, a scale of convenient measurement may be formed.

* A compound from the Greek, κυανος, the *colour of the sky*, and μετρεω, *to measure*.

142. A very beautiful specimen of natural phenomena frequently presents itself to our notice, under the general name of *halo*. In the northern regions, the sun and moon frequently appear surrounded with halos or *coloured circles*, having a diameter of about 44° or 92°. A halo round the *sun* is termed a *parhelion*;—round the *moon*, a *paraselene**.

143. The cause of these circles has been thus explained by Dr. Young. Crystals of ice and snow always tend to form angles of 60°; and it has been found, by experiment, that a prism of water or ice, whose refracting angle is 60°, produces a deviation of $23\frac{1}{2}°$ in the direction of a ray of light passing through it:—that is, if a ray of light impinge on this prism at such an angle as to pass through the prism parallel with its base, a deviation of $11\frac{3}{4}°$ will take place at each surface, making $23\frac{1}{2}°$ in the whole. Now, if such prisms of water or ice were placed at all possible angles of inclination, differing equally from each other, one half of them would be so situated as to be incapable of transmitting any light regularly by two successive refractions directed the same way; but the other half would send refracted and coloured rays to the eye. It has been supposed, therefore, that there are particles of snow, or crystalline vapour, suspended in the air, each particle being of a prismatic form; and, as these may occupy every imaginable position with respect to each other, we may conceive that a circle of them might encompass the line drawn from the luminary to the eye; and that the light, refracted and dispersed into its coloured elements by those little prisms, would give rise to a coloured circle apparently surrounding the sun or moon. This gives a circle, whose radius equals the deviation, that is, $23\frac{1}{2}°$; or a diameter of 47°.

144. This theory is applicable to halos, both of the sun and moon. They are frequently produced by a reduction of temperature, which causes a sudden congelation of the watery particles in the higher regions of the air. All these phenomena are very variable, and no two recorded descriptions agree with each other; but, as it is the business of science to imitate, and account for, the productions of Nature, the theory of halos may be conveniently illustrated by the following imitative experiment:—Upon a flat piece of glass, spread a few drops of a strong solution of alum:—put this in a warm place; upon the chimney-piece, for example. The solution will crystallize quickly, and will leave upon the plate a crust composed of flat octohedral crystals. If the observer place his eye close behind the smooth

* These words are compounds from the Greek;—*παρα*, *near*, *ἥλιος*, the *sun*, and *σεληνη*, the *moon*.

side of the glass, and look at a luminous body, he will perceive three fine halos, at different distances, surrounding the source of light.

145. Coronæ, or *crowns* of light, are small halos round the sun and moon in fair weather, when light fleecy clouds are much about either luminary. A solar corona is best observed by reflexion from water. They are accounted for by Dr. Young's theory.

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146. We now conclude the subject of the Prism. We are about to invite the student to enter with us upon kindred inquiries, which are equally pervaded by the immortal genius of Newton,—a genius, which, as we have already remarked, can be fully appreciated only by the diligent student of Nature. A great and exalted mind can be well estimated only by another mind, which, if not of itself great, contains at least within itself the elements of greatness. But it will be enough for his present purpose, if the student have acquired for his mind that tension, force, and exactness, which well-regulated study induces. If, by an earnest contemplation of those discoveries which will never die, he be inspired with an ardent love of truth, he will at once admit the justice of the high encomium, which the eloquent Chalmers has bestowed on the man whom every student ought to look up to as his model, and follow as his guide. "When we look back on the days of Newton, we annex a kind of mysterious greatness to him, who, by the pure force of his understanding, rose to such a gigantic elevation above the level of ordinary men—and the kings and warriors of other days sink into insignificance around him—and he, at this moment, stands forth to the public eye, in a prouder array of glory than circles the memory of all the men of former generations—and, while all the vulgar grandeur of other days is now mouldering in forgetfulness, the achievements of our great astronomer are still fresh in the veneration of his countrymen, and they carry him forward on the stream of time, with a reputation ever gathering, and the triumphs of a distinction that will never die."

X.

THE TELESCOPE.

First in his east the glorious lamp was seen,
Regent of day, and all th' horizon round
Invested with bright rays, jocund to run
His longitude through heaven's high road; the gray
Dawn, and the Pleiades before him danc'd,
Shedding sweet influence: less bright the moon,
But opposite in levell'd west was set,
His mirror, with full face borrowing her light
From him, for other light she needed none
In that aspect, and still that distance keeps
Till night; then in the east her turn she shines,
Revolv'd on heaven's great axle, and her reign
With thousand lesser lights dividual holds,
With thousand thousand stars, that then appear'd
Spangling the hemisphere: then first adorn'd
With their bright luminaries that set and rose,
Glad evening and glad morn crown'd the fourth day.

MILTON, *Paradise Lost*, B. 7.

INTRODUCTION. ON THE STATE OF ASTRONOMICAL SCIENCE PREVIOUS TO THE INVENTION OF THE TELESCOPE.

1. THERE is assuredly no spectacle in nature so fitted to command our admiration, so calculated to inspire us with a lofty idea of the power and all-pervading wisdom of the Deity, as

The spacious firmament on high,
With all the blue ethereal sky.

Can we wonder that both the sage and the savage have in all ages looked at this wondrous mechanism with feelings of awe and reverence?—the savage with ignorant wonder blended with his admiration, or with his fear, according as the influence of the heavenly bodies on his destiny was supposed to be good or evil. But it is the sage—the philosopher—the man of thought and reflection, who is best fitted to measure the incomparable superiority of such productions over all that man can do. No one knows so well the real ignorance of human nature as the philosopher;—by which we mean, that the more we explore and investigate the works of Nature, the more capable do we become

of perceiving their perfect excellence, when compared with the result of man's ingenuity; and the more assured are we that there is a guiding hand which rules and governs all. The man of uncultivated mind views these splendid scenes (if he view them at all) with gaping wonder, not unmixed with awe and dread: what he sees is so wonderful, and so much above the general tone of his thoughts, that he is afraid to think of them; or, if he do suffer his thought to dwell for a short time on such a subject, the vastness and immensity of the field causes him speedily to shrink into himself, and to shroud his ignorance under the plea that it is presumptuous in mortals to endeavour to understand the mighty works of the Deity. But the philosopher, when he considers what incalculable benefits mankind has derived from the increased knowledge of the laws which Nature has impressed upon all her productions,—when he reflects on the noble trains of thought which pass through the mind of the man who has studied those laws,—when he looks around, and finds that those, in whom vulgar prejudice and ignorance of natural phenomena are prominent features, are often precisely those in whom the moral sentiments are at the lowest point,—when he observes that narrow and mere conventional prejudices are less observable in men of science or of general cultivation than in those of crude, uninformed minds: when he sees and knows that all this is so, he cannot hesitate to believe that it is good and proper for man to endeavour to become acquainted with those sublime and simple laws, the due observance of which conduces to his well-being, and the defiance of which entails a sure and just penalty.

2. Astronomy, of all other sciences, affords the most numerous proofs of the effects to which we have just alluded. No longer ago than 220 years, it was deemed almost a crime to point a telescope to the heavens; as if the beautiful starry dome would be injured, or its divine Creator offended, by the admiration of man. An inquiry into the life of the great Galileo teaches us how far ignorance of Nature induces a system of inquisitive cruelty and persecution towards those who wish to extend the knowledge of her laws. We, who live in days when the free exercise of thought is open to all, can hardly conceive the bitter and painful persecution, to which men were subjected in by-gone ages, if they dared to study the book of Nature. Let us conceive what would now be our feelings, if, through any mighty change in the social condition of man, he were debarred from the pleasure of studying the mechanism of a flower, and the phenomena connected with its growth;—the motion of the

heavenly bodies, and their influence upon the earth;—the physical, chemical, and medicinal properties of this earth's productions and their applicability to the uses of man. We know, we feel, that we possess the valuable privilege of doing all this: and this consciousness forms a link in the chain, which binds man to man in one great fraternity: and it is a bright and cheering thought that those who come after us, will inherit the privilege of studying nature, and of improving upon those discoveries, which the present and previous ages have accomplished.

3. This train of reflexion has been engendered by a consideration of the mighty change in the current of human thought, which has been brought about by the use of the *Telescope*. Truths, which would have been thought not only idle dreams, but presumptuous speculations, are now known and acknowledged by the reflecting portion of every country in the civilized world. This has been done; and yet mark the result,—no one now pretends to exercise an influence upon the motions of the heavens in consequence of his increase of knowledge: but time was, when the science of Astronomy was aided,—only incidentally,—by the pursuit of astrology, or divination by the stars; as chemical knowledge was fortuitously enlarged by the day-dreams of the alchemists. We know more than ever was before known respecting the number, the appearances, and the motions of these orbs of light; yet we are as dull to conceive, as before, the wondrous power and method by which the whole was produced into being by the Great Creator, marshalled, each into its appointed place, and then disposed into motion:—for ever thus to move, till the same Mighty and Original Power shall alter, or command an entire cessation.

> With what an awful world-revolving power
> Were first the unwieldy planets launch'd along
> The illimitable void! thus to remain,
> Amid the flux of many thousand years,
> That oft has swept the toiling race of men,
> And all their labour'd monuments away,
> Firm, unremitting, matchless, in their course;
> To the kind-temper'd change of night and day,
> And of the seasons ever stealing round,
> Minutely faithful: such the All-perfect hand!
> That poised, impels, and rules the steady whole.

He whose mind is duly imbued with a love for the sublime and the true, is not likely to manifest, in consequence of increased knowledge, that presumptuous arrogance and self-conceit, which have been supposed by those, who have not suffi-

ciently attended to the subject, to be natural attendants upon a partial increase of a knowledge of the laws by which the physical world is governed.

4. Before treating of the telescope, we will briefly detail the principal facts connected with the motions of the heavenly bodies, which had been observed and recorded prior to the use of this instrument:—and we shall thus be able to see how far that invention exerted an influence on the progress of Astronomical knowledge.

5. If we attentively note what are the occurrences, or phenomena, which present themselves to our notice in the heavens during a day, we find that a splendid and glowing sun travels, as it were, through an ocean of light, from east to west, gaining its greatest altitude above the earth's surface at the middle of its path, and shedding light, and heat, and exuberance on all around. We then see that, as he approaches towards the western limit of his journey, the light and heat derived from him are diminished, and symptoms of change are susceptible in various ways. As the sun dips below the horizon, or removes from our view, we see that other smaller suns begin to show themselves; as if respect for the nobler orb of day had hitherto kept them in retirement. These little twinkling suns increase in distinctness, and in number, as the increasing distance of the sun below the horizon more effectually prevents his beams from reaching the part of the earth, on which we stand.

Thus, these miniature suns, or stars, seem to spring into existence out of nothing, or of nothing which we can see, except that which we call *the sky:*—they do not appeal to our notice by first appearing in the east, as the sun had done some hours before; but they begin to appear at nearly every part of the heavens at once, and thus look like fixed residents in the points of the heaven at which we view them. Soon, however, we find that they are not fixed, but that they change their places—not with regard to each other, but as a whole or system—with the same rapidity as the sun had done; and that that change of position bears a general similarity to that of the sun; namely, that the points of the star's disappearance beneath the horizon are, as a general rule, towards the west. We likewise see that, as various sets of stars disappear beneath the horizon, another part of this twinkling panorama is being shifted up from the east. This regular travelling of the little silvery suns towards the west continues uniformly to proceed, until a gradual change of scene takes place in the east:—it is observed that a gleam of light, independent of that of the stars, begins to streak

the heavens, and, as it does so, is accompanied by a diminution of the lustre of the stars in that quarter. This increase of eastern light is every minute made more manifest, until at length a glorious gush of light appears rising from the distance;—as if a fiery messenger were sent to tell the stars, their nightly task was done: and we now see that the rising orb is similar to that, which had sunk beneath the horizon on the evening before. The path which this orb,—"the day-star," as the poets term him,—had taken on the preceding day, is again traversed; and his disappearance in the west, and the consequent loss of light to the earth, are again followed by the splendid display of stars moving westward, as before.

6. But there is another phenomenon independent of all that we have been speaking of, and which does not present quite the same features. On some particular day we see that the sun, just before he sinks into the west, is accompanied at a short distance to the left, by a narrow crescent of light, whiter than that presented by himself; and that the convex side of this crescent is nearest to the sun. It soon sets or sinks below the horizon, and we lose it. On the next day when the sun again appears, we look for his companion of the previous day; but do not see it: he travels through nearly the whole of his semicircular path towards the west; but it is not until he nearly approaches this latter point that we again see his crescent-formed attendant. We now observe that the appearance of the crescent is not quite the same as that of the previous day. It is thicker at the middle, and is at a greater distance from the sun: but further observation is soon checked by the disappearance of both beneath the horizon, and we have to wait till the following day for further information. We then find that the crescent becomes faintly visible before the sun approaches the horizon, and that the thickness of the crescent and its distance from the sun are both greater than on the previous day; which latter circumstance enables the crescent to shed an increased light on the earth for the short period of time that it remains above the horizon after the sun has set.

This change we notice for several days, until, at about five or six days after the crescent was first seen, the form becomes a perfect semicircle, and its distance from the sun is so far increased, that, when the latter is setting in the west, the former is high in the southern heavens, and has therefore a track of several hours' duration to travel between the sun's setting and its own disappearance beneath the horizon, during which time it sheds a quiet and beautiful light upon the earth; and, as it is felt to

afford no warmth to cheer up the dampness of night, we feel the truth of the character given of it by the poet, "the chaste cold moon." Again, observing day by day the phenomena presented by this variable body, we perceive that the distance between it and the sun is continually increasing, and that, at the same time, the size of the body itself increases; until at last we perceive that it becomes perfectly circular, and is situated at the distance of a semicircle from the sun; that is, when the sun is about setting in the west, the moon is rising in the east; and that, when the one is at its greatest depth below the horizon, the other is at its greatest elevation above it.

7. Now all this, which we see constantly repeated, was seen in the same way and under similar circumstances, by the primitive inhabitants of the earth. Is it not then natural that such a splendid assemblage of phenomena should have attracted their notice and riveted their attention? The calm and clear atmosphere of Chaldea and Judea was peculiarly favourable for the purpose of observation on the motions of the "heavenly host." When the inhabitants of those regions saw that the sun rose constantly with the beginning of each day, and that it set as constantly in the west, they could not fail to conclude that the same sun, which set in the evening, rose again the next morning; and, in order that it should effect this change of position, it was manifest that it must have performed a retrograde motion under the earth, in order to arrive again at its rising-point. Hence came an important conclusion,—that the sun, without any deviation from the circular form, revolved round the earth every day. We are satisfied, from the evidence which they have left behind them, that the Chaldeans did not long retain the ignorance which Mungo Park found among a tribe of people in central Africa; whose opinion it was that the inhabitants of the west *fired* the sun, when he got down to them, and, after heating him for next day's service, took him round by a private passage to the east.

8. The variable orb of the moon, we may suppose, may have next attracted their attention. The changes in appearance and position, which we have above detailed, occurring, as they did, in the course of a few days, presented too marked a phenomenon to escape notice. After the changes from the crescent-form to the circle, the moon gradually approaches the sun in an opposite direction; that is, its distance becomes less than a semicircle. At the same time it is observed that its form begins to undergo a change, by one side of it becoming flatter, while the other remains convex—the side which is now variable being that which was before constant. This change goes on for about seven days,

when it is found that the moon is high in the southern heavens, at the time that the sun is rising; whereas, a fortnight before, when the moon was at her highest point, the sun was about setting; and as the convex side of the moon was towards the sun in the first instance, and has since reversed its position, it follows that in both positions the convex or circular side of the moon, is towards the sun. These diminutions in size, and in distance from the sun, continue until the moon is again so close to the sun, that the faint crescent, which is all that now reflects light to us, is lost in the flood of solar brightness.

9. Now all these phenomena are very perplexing to the mind, which has not obtained some previous knowledge of the laws of reflexion of light. Two questions arise from the observance of these phenomena:—1st, How can the gradually increasing distance of the sun from the moon be reconciled with her subsequent approach towards him? 2nd, From whence do the bright portions of the moon, by which its size is increased, emanate; and what becomes of the bright portions, which, by their disappearance, again reduce the circular to the crescent form?

10. What a mass of crude theory must be employed to give even a rough approximation to an answer to these questions, unless the doctrine of reflected light be brought to bear upon them! Let us inquire in what way we can produce a series of phenomena, representing the change of distance between the sun and moon. Suppose we stand at a distance of two yards from a candle, and hold a gilt ball or an orange at arm's length from us. When we hold the ball between the eye and the candle, the latter is eclipsed by the ball; and there is from the point at which we see them, no *side-long* distance between the two. Let us now move the ball a little on one side, so as to obtain a view of the candle: we then appreciate a small distance between the two; that is, a small *angular* distance; for that is the species of distance which we are now considering. On gradually moving the ball on, the distance between it and the candle increases, until the maximum distance is obtained, when the ball is directly away from the candle; for then the head must turn round a semicircle to look from one to the other. If we now continue the circuit, we find that the distance of the ball from the candle begins to decrease, and this decrease continues until the ball finally comes again between the eye and the candle.

If we compare this series of results with that presented by the moon, can we fail to see a resemblance? The gradual in-

crease of distance,—the maximum distance, when the head has to be turned a semicircle in order to look from one to the other,—and the gradual approximation towards each other on the opposite side,—all point to the conclusion, that a revolution of the moon round the earth produces, in the one case, the effects which we know a revolution of the ball round the head of the observer does in the other: and thus we may, without straining the power of analogy any further, answer the first question.

11. In order now to obtain an answer to the second question, let us assume that the moon is an opaque body, shedding no light of her own upon the earth, but that her surface reflects light derived from other sources: let us suppose also the moon to be a globe, and the sun to shine upon her as freely as he does upon us; it will then not require much reasoning to be convinced that the different *phases*, or *appearances*, of the moon arise wholly from the quantity of reflected light which happens to reach the earth from the moon at any given moment of time. If we place the gilt ball, or the orange, assumed in the former instance, between us and a lighted candle, we see only a black round ball. When we hold it at a quarter of a circle from the candle, we see exactly half of the disk formed by the ball illuminated, the convex side being towards the candle: the faint view which we may have of the other half being due to irregular reflexion from the walls and ceiling of the room. If we now move the ball more nearly in a line with ourselves and the candle, we shall see more than half the disk formed by the ball; and as we increase the angle made by the ball and candle with the eye, the illuminated part of the ball becomes still larger, until at length, when the candle, the eye, and the ball, are in a line (except that the head must be a little lowered to allow the rays of light to fall on the ball), the latter then appears as a perfect circle. By continuing the circuit, the side most remote from the candle begins to lose some of its convexity of appearance, and gradually becomes flattened; until at length, when it attains such a position that a line drawn from the eye to the ball, and another from the ball to the candle, shall form two sides of a square, we shall see exactly half the ball, the other half being shrouded in darkness. On further advancing the ball, so that it shall gradually approach the candle, the illuminated portion becomes of a crescent-form, and decreases in size until at length it again assumes the appearance of a black ball, being then exactly between the eye and the candle.

12. Now, if we compare this routine of changes with that described as occurring with the moon, we cannot fail to be struck with the analogy between them; the increasing size of the cres-

cent as the illuminated ball left the candle, and of the moon as it left the sun: the continuance of this increase until both had attained a circular form, at the greatest distance from the luminous body: the gradual decrease of illuminated surface, as the moon and the ball approached the luminous body: and the transfer of the convexity of the illuminated surface from right to left, according as it was on the left or the right of the sun or the candle:—all give evidence of the strongest kind that the moon, besides sharing with the sun a daily motion round the earth, has a motion of her own in the opposite direction, which motion is completed when the *phase* or *aspect* of the moon is the same as when it set out; and this embraces a period of $29\frac{1}{2}$ days. If our readers will take a clean ball of any substance, and carefully note the variation in its appearance when held in different directions with regard to a candle, (there being no other light in the room,) they will thus get a perfect representation of the changes in the appearance of the moon.

In this way we may suppose the early observers to have reasoned; at least those who excluded the idea that the moon shines from any native light of her own; and thus to have laid the groundwork for a series of observations on the phenomena connected with her.

13. But, we have now to speak of another train of events which a watchful attention to the appearances of the heavens is likely to reveal to us. If we look at the splendid assemblage of stars, when the sun is beneath the horizon, we perceive that, although the whole of them move from the east towards the west, and thus perform their daily, or rather *nightly* journey, yet they retain the same relative distances from each other. If we see three bright stars in the form of a triangle, and near them four others forming a square, we shall see the triangle and the square unaltered in form, night after night. At one hour of the night, certainly, we may see the triangle as if it were resting on its base; and at another hour as if resting upon one of its angles; yet the form of the triangle is unchanged; and, if two of the three stars which form it were in a right line with one or more of the stars composing the square, that right line will be observed at all hours and on all nights that the stars are visible, whether the square be over, or under, or at the side of the triangle: this is what we mean when we say that the stars do not change their positions with respect to each other.

14. But the law, which successive observations of the phenomena of the heavens, for several nights, will reveal to us, will be found, after a certain amount of observation, to be not rigorously true in all cases. It will be noticed that there are a few

brilliant stars, say three or four, which do not retain, night after night, the same relative distances from certain other stars; but seem to be variously situated with regard to them, and to themselves, at different periods. On one evening, for instance, we may see one of them forming the centre of a kind of polygon of stars, and presenting an appearance similar to them. The same appearance will be found for, perhaps, two or three evenings; but on the fourth we become sensible of a change in the relative positions of these stars: the polygon is there, as before, with all the stars which form it in the same relative condition as when first observed; but the centre of the polygon is no longer the same. The star which formed it has moved off to the side. A few evenings afterwards the star is seen to have escaped altogether from the circumscribing limits of the polygon, and to increase its distance from it night after night. Another star may be seen forming a right line with two other stars, being either at the middle or at the end of the line. But in the course of a few evenings this rectilinear position is no longer observed: two of the stars retain their places as before, but the third has varied; it has either removed farther from the other two, or approached nearer to them, in the same right line, or otherwise; and, if the former be the case, it will not long remain so, for the departure from the rectilinear position always occurs in a short time.

15. Again, these changes occur not only with respect to the other stars, but also with respect to the sun and moon. We may see a star which, from its resplendent brilliancy, we are not likely to mistake for others, high in the heavens at the time that the sun is sinking below the horizon, and therefore eastward of the sun: but in some considerable time afterwards we may see the same star at a considerable elevation at the moment when the sun rises, and therefore westward of the sun. We may further detect a variation in the size of these three or four *moving* stars; a phenomenon which does not occur with the stars which never change their relative places.

16. Now all this must, in the course of time, have been presented to the early observers. The sun, being the most brilliant and effective body of the whole, must first have drawn the notice of men to his motions. Then the glittering, twinkling stars, the "holes in the floor of heaven, to let the light through," as the simple negro once interpreted them, must have shared with the sun in exciting the admiration and attention of beings upon earth. Then the moon, with all the varying appearances of size, form, and position; and lastly, the few *moving*

stars, presenting, in their motion, an exception to the general rule which appears to govern the other stars, were calculated to keep alive the spirit of inquiring wonder, which the former had inspired.

17. Gradually, and by insensible degrees, we may imagine that the laws, by which these beautiful phenomena were regulated, became the object of inquiry among the early nations. The conviction that the sun was a luminous body and shone by virtue of that luminosity, and that it revolved round the earth, was, we may suppose, succeeded by the impression that the moon also revolved round the earth in about one day, as did the sun; but that she possessed an additional motion of her own, by which she was carried round the earth in 29½ days; and that she shone, not by any native light of her own, but by light reflected from the sun. The latter conclusion was, however, of posterior date. These phenomena, presenting themselves frequently and regularly, might have afforded the means of their own explanation more readily than those of the three or four moving stars. The motions of the latter, as indicated either by their distance from the sun, or from any other stars, is found to be less rapid than that of the moon: that is, if the sun, the moon, and one of these moving stars, were at certain rectilinear distances on any one evening,—if they were observed on any subsequent evening, the distance of the moon from the sun would be found to be much greater than that of the star from the sun.

This tardiness in the motion of these moving stars would prevent the nature of that motion from being detected as readily as the motion of the sun or moon might be. But, at the expiration of a long period, it would be seen that the moving star attained exactly the same position with respect to the sun that it had at the beginning of the period; and thus would arise the idea, that the moving star had a revolving motion of some kind, but whether round the sun, or round the earth, subsequent observation would be necessary to determine.

18. It will be felt that all this may be observed without the aid of any optical instrument, except that which is the most exquisite of all—the human eye. The sun, the moon, the fixed stars, and four of the *moving stars*, or *planets* may all be seen with the naked eye; and we may, therefore, be prepared to expect that many important facts connected with their motions might be discovered long before the invention of optical aids for that purpose: we here speak of but four of the planets, because the others, such as Mercury, Uranus, and the four small planets, are not so easily seen as the others.

Accordingly, we find that a range of important phenomena connected with the motion of the heavenly bodies was known and appreciated in very remote ages; when Europe, if inhabited at all, was inhabited by men who have left no traces of their existence behind them.

We learn from Josephus, that Seth and his posterity, who were the earliest denizens of the world, had much Astronomical knowledge. He speaks of two pillars, once in existence, the one of stone, and the other of brick, called the pillars of Seth; whereon were engraved the principles of this science.

The Chinese, the Hindoos, the Chaldeans, and the Egyptians, were the four nations, which studied the appearance and motion of the heavenly bodies at the most remote periods. Researches the most profound, and talents of the most brilliant order, have been devoted to the inquiry as to which nation first made definite and important discoveries on the subject. But those researches have not much cleared up the question proposed. The information gained respecting the progress of Astronomical knowledge in the early ages, is most important and valuable; but it is not yet known who were the first to leave authentic records on the subject. Nor is it wonderful that such should be the case. The existence of documental or even monumental evidence for thousands of years is uncertain and precarious; and the many occasions, on which the boastful vanity of a writer has given to his race or country an antiquity greatly exceeding the truth, serve to show how likely misconception is to arise in the minds of those who read such authors, unless they be sedulously on their guard against such exhibitions of vain boasting. Hence, two commentators or translators, equal in merit and knowledge, may give very different versions of an ancient manuscript, or inscription, according to the degree of credit which they attach to the writer, or to the amount of prejudice which they bring to bear upon the question at issue.

Whichever nation, however, had the merit of first recording observations on the heavenly bodies, it is plain, that a large amount of knowledge had been accumulated long before the existence of any genuine documents, if we except the Bible, throughout which there are interspersed, at intervals, several notices of an Astronomical complexion.

19. We have spoken of the sun, the moon, the fixed stars, and the moving stars, or planets; and we have exhibited the probable train of reasoning, by which the first observers would conclude that each of these classes of bodies has a motion, real

or apparent, independent of, and different from, each of the others. But much more than this must have been very early known; for we find that eclipses and their cause were known by the Chinese at a very remote period. There is among the Chinese annals, a record concerning a particular position of the heavenly bodies in or about the year 2461 B. C.; that is to say, the four planets, Mercury, Mars, Jupiter, and Saturn, together with the Moon, were all assembled in the constellation Pisces. This meeting of planets in the same sign is called a *conjunction.* A writer of Chinese history has calculated that, about that period, this conjunction really did occur. This calculation is obtained by reckoning backwards, year by year, according to the periodical motions now known to be performed by these heavenly bodies. Doubts have, however, been expressed concerning the accuracy of these retrograde calculations, by reason of the imperfection of the tables used in the work;—but, be they correct or not, any record of an appearance in the heavens at that remote period is interesting, if we have no reason to believe it to be altogether spurious.

20. There is one circumstance which may be urged in favour of those ancient records; which is, that the Chinese and Hindoos have been accustomed to reckon, as an epoch of time, a conjunction of several planets at a remote period; and the very attempt to fix the time of that epoch is illustrative of early attention to the subject, whether with a correct result or not. The Chinese were, from an early period, acquainted with the obliquity of the equator to the ecliptic; that is, the path which the sun follows in the heavens from sunrise to sunset on any one day, is not exactly the same as that pursued on previous and succeeding days. Now this becomes very perceptible after the lapse of weeks and months; and hence, the noon-tide altitude of the sun, or his greatest height above the horizon, which is at that time of the day, being at one period of the year greater, and at another less, is due to this gradual diverging of the ecliptic, or sun's path, from, and recurrence to, the equator, or central line which divides the earth, as to its rotatory motion, into two equal parts. They were also acquainted with the precession of the equinoxes, which is, an annual westward shifting of the point where the planes of the equator and ecliptic cut each other. An eclipse of the sun is recorded as having occurred about the year 2128 B. C.; which, we are told, Schong-Kang, the emperor of China, was so exasperated against two of his great officers of state for not predicting, that he ordered them to be put to death. This account, if true, seems to convey the fact

that the power of calculating and predicting the occurrence of eclipses was possessed at that early period.

21. The Chaldeans were acquainted with a very long period of $6585\frac{1}{3}$ days, during which the moon performed an integral number of revolutions, with respect to the sun and the earth; and this shows an extensive knowledge of the phenomena presented by the moon, as this tabular period was the groundwork of their predictions of lunar eclipses. The Egyptians and the Chaldeans were also well acquainted with the fact that the year does not consist of an exact number of days; but that $365\frac{1}{4}$ was the proper number to be taken. Now, when we consider that the most correct statement of modern times gives 365 days, 5 hours, 48 minutes, and 48 seconds, as the length of the year, we cannot fail to observe the near approach to accuracy made in those early ages. The Indians and Hindoos also appear to have devoted great attention to these points, principally with reference to eclipses, a class of phenomena which has ever been regarded in the East with superstitious veneration, as being supposed to exert great influence on sublunary affairs.

Atlas, an African monarch, who lived perhaps 2000 years B. C., was accustomed to ascend a high mountain to view the heavens. This mountain-range still retains his name; and he himself was fabled by the poets to have supported the celestial sphere on his shoulders.

22. These are a few of the particulars gleaned by modern astronomers respecting the knowledge which the early Eastern nations possessed of the motion of the heavenly bodies; and it may be seen that this knowledge is of a nature not requiring the aid of optical instruments; although some mathematical ingenuity and great patience of observation must have been exercised. The same remarks apply to subsequent ages. The Greeks made great progress in Astronomical knowledge through the means of their refined geometrical skill, and the general tone of intellectual cultivation which distinguished them. One by one, important discoveries were announced; some being altogether new, and others similar to, but tending to disprove, the mere theories or assertions of previous writers. The more ancient Greeks used to seek the North by observation of the constellation, called the Great Bear, until Thales, about 600 B. C., taught them to do so more effectually by observing the Little Bear. Pythagoras, we are told, about five centuries before the Christian era, taught the doctrine that the earth revolved round the sun, and not that the sun revolved round the earth,

as the testimony of our senses indicates. Hence, Thomson, in his poem on *Liberty*, speaking of Pythagoras, says,—

> His mental eye first launch'd into the deeps
> Of boundless ether; where unnumber'd orbs,
> Myriads on myriads, through the pathless sky
> Unerring roll, and wind their steady way.
> There he the full consenting choir beheld;
> There first discern'd the secret band of love,
> The kind attraction, that to central suns
> Binds circling earths, and world with world unites.

We said in our former remarks that the recurrence of several successive appearances of the heavenly bodies above the horizon, gradually gave rise to the idea that they all revolved round the earth. But it required a wider grasp of intellect to come to the conclusion, that the same train of effects would follow the motion of the earth round the sun; and it is a lamentable instance of the degradation of intellect, after the brilliant age of Grecian history, that the doctrine of Pythagoras became repudiated, and that nearly 2000 years elapsed before the complete establishment of the opinion of Pythagoras respecting the motion of the earth we live on.

23. In our Prayer-books and Almanacs we see a column designated the "Golden Number*". This is the ordinal number of any year in the Lunar Cycle, and first resulted from a contrivance by Meton and Enctemon of Greece, 433 B. C., to render the relative positions of the sun and moon exactly the same after every interval of nineteen years, which was called *the cycle of the moon's changes*. The object of this arrangement was, that there should be certain periods known, at which the sun and moon would commence, the one an *annual* or *yearly*, and the other a *menstrual*, or *monthly*, revolution at the same moment. This was brought about by adding a day to the lengths of some of the months at certain periods; and it has been continued, with some improvements, up to the present time. As several of the Feasts in the Christian Church depend for their date on that of Easter-day, and as this latter depends upon the age or situation of the moon, this adaptation of the Golden Number must necessarily bring the time of the full moon preceding Easter-day exactly on the *same* day after the recurrence of the nineteen years mentioned before.

24. When the vast and ill-assorted empire of Alexander the Great became dissevered after his death, the Egyptian por-

* So called from having been engraved on gold in the market place at Athens, and written in gold letters in the almanacs of later times.

tion of that empire fell under the dominion of men, who greatly advanced the progress of Astronomy. This was about 300 years before the Christian era. Ptolemy Lagus, the first king, and those who succeeded him, collected a magnificent library, and established a regular system of astronomical observations. Hipparchus, who was fostered and encouraged by Ptolemy, discovered that the orbit in which the sun revolves annually, is not a circle but an ellipse, and he determined very nearly its *excentricity*, that is, the amount of the deviation of an ellipse from the circular form. He formed tables of the motions and phenomena presented by the sun and moon;—he prepared a catalogue of the fixed stars, and was the first to suggest the mode of determining the position of any place upon the earth by its latitude and longitude, measured from two given great circles of the earth, and computed by means of the motions of the heavenly bodies. The catalogue of the stars, imperfect as it must necessarily have been, was so important an element in all subsequent observations, that it has obtained for Hipparchus the appellation of "the Father of Astronomy."

25. After Hipparchus, Ptolemy of Alexandria in Egypt, who flourished about 140 years after Christ, collected the scattered materials which had been accumulating from different sources, and formed the first system of Astronomy, which served to lay the ground-work of future treatises on the subject; but, unfortunately for his own fame, he discarded the opinion of Pythagoras respecting the earth's motion round the sun, and advocated the contrary opinion, that the sun revolved round the earth; and, as a consequence, that the planets revolved round the earth also. The order which he gave to them in his ideal system was this: that the moon revolved in an orbit nearest to the earth, and that Mercury, Venus, the Sun, Mars, Jupiter, and Saturn, performed similar revolutions, but each one in an orbit successively larger in proportion to its distance from the earth: and lastly, which seems to us the most cumbrous part of the theory, that the whole dome of the fixed stars revolved exterior to the rest, encompassing this earth and all the planets as with a concave crystal sphere, the earth being stationary in the centre of the whole. These motions he also believed to be circular, and not elliptical, from some fanciful notions respecting the perfectibility of a circle. These erroneous opinions, which detract somewhat from the credit of a man, otherwise great as an astronomer, were not thoroughly disproved until the time of Copernicus, several centuries afterwards.

26. After this period, a blank occurs in astronomical discovery, until the time when the propagation of the Mohammedan creed produced many new features in the aspect of Eastern society. The Arabs, about the eighth century, began to display much ardour in the prosecution of astronomical observation. Haroun-al-Raschid, the caliph of Bagdad, the cotemporary of Alfred the Great, and of the Emperor Charlemagne, about 800 A. D., gave most liberal encouragement to learned men, especially to astronomers. The Arabs determined, within $3\frac{1}{2}$ minutes of a degree, the obliquity of the ecliptic to the equator: they measured an arc of the meridian, to determine the length of a degree in cubits: they computed, with greater precision than had been previously done, the form of the ellipse of the earth's orbit, and the precession of the equinoxes. They also made other calculations of an intricate and difficult character. The Tartars, who, under Gengis Khan, subjugated the greater part of Asia, at the beginning of the thirteenth century, likewise cultivated Astronomy with much success. One of them, Ulugh Beg, the grandson of Timour, or Tamerlane, made a very extensive catalogue of the stars, which to this day is held in great repute by Oriental nations.

27. Among the Christian nations of Europe the study of Astronomy made but little progress until comparatively recent periods. The Romans never greatly encouraged the cultivation of this science; and the attention bestowed on this subject, before the thirteenth century, was chiefly for the purpose of rectifying the Calendar, by introducing such amendments as would make the duration of the year in civil life coincide with the commencement and termination of each revolution of the sun; that thus appointments made for particular seasons, and for particular days at the lapse of certain times, might not fall respectively upon a day sooner or later than had been settled by common consent.

28. Alphonso X. of Castile, occupying a medium position between the Moorish sovereigns of the south of Spain and the Christian countries of Europe, was the means of amalgamating the knowledge gleaned by both; and under his auspices was prepared an extensive series of tables of the motions, positions, &c., of the heavenly bodies, which tables were called, from the sovereign, the Alphonsine Tables. After this period, men sprang up, one by one, unfolding powers of mind and intensity of application, which gradually extended and enlarged the sphere of astronomical knowledge. Purbach, Müller, and Walther, began to shake the hold which the theory of Ptolemy

respecting the motion of the sun round the earth had maintained, and thus to pave the way for a brilliant career of modern improvement.

29. Copernicus, who may be regarded as the first in order of modern astronomers, revived at the beginning of the sixteenth century, after forty years' patient reflection, the doctrine which had slept for 2000 years, that the sun is the great body, round which the earth revolves. He conceived (what is now known to be true) that the whole of the planets, the moon included, revolved round the sun, in the following order, beginning from the nearest to the sun:—Mercury, Venus, Earth, Mars, Jupiter, and Saturn, and that the moon had a motion round the earth, and, with it, a common motion round the sun. Thus began a splendid series of observations, free from the contamination of crude theories, because every successive fact or discovery tended to confirm the view which Copernicus had taken of the general motions of the heavenly bodies; although in minor points he had made conjectures, which did not stand the test of inquiry; such as that the orbits of the planets round the sun were circular: but, by such a supposition as this, the fundamental principles of the solar system, as now received, were not compromised.

30. He was shortly followed by Tycho Brahè, a Dane of great penetration of mind; who, in the middle of the sixteenth century, made a more accurate catalogue of the stars than any one who had preceded him, and formed a table respecting the distortions in the appearances and positions of the heavenly bodies, due to the refraction of light by the earth's atmosphere, a subject first noticed by Ptolemy of Alexandria. He made many important corrections in the theory of the moon's motion, and greatly improved the mode of explaining the nature of the motions of comets, a subject ill understood before his time. But it is singular that, with all his powerful and industrious research, he should have partially rejected the Copernican system of the universe. We have said that Ptolemy supposed all the planets, including the sun and moon, to revolve round the earth, which remained fixed in the centre. Copernicus taught that all the planets revolve round the sun, as their centre. But Tycho Brahè took up a medium position between the two, and argued that Saturn, Jupiter, Mars, Venus, and Mercury revolved round the sun, and that the whole of them in an immense body, with the sun in the centre, revolved round the earth, which remained a fixed point at the centre. His object in theorizing thus was to conform in some degree with

the justice of the new opinions; and, at the same time, to keep faith with the language of Scripture, which, he should have remembered, is sometimes literal, at other times figurative, and is addressed to man, not in his scientific character, but with a view to his condition by nature and by grace. The chief argument, by which Tycho Brahè opposed the notion of the earth's *diurnal* motion, was that, if we suppose the earth to revolve on its axis, and a stone to be dropped from the top of a tower on the side opposed to the motion of the earth, that is, on the western side, the stone would fall several feet from the base of the tower; because, while the stone was falling, the earth and the tower upon it, would move through an appreciable space;—a space of several feet. There are many persons at the present day, who, not sufficiently attending to the laws of the physical phenomena occurring around them, have argued in a similar strain. But we may show, as Rothman showed to Tycho Brahè, that every thing upon the earth's surface partakes of the motion of the earth; so that, if a stone fall from a perpendicular height, it will at the moment of falling, be possessed of that curvilinear tendency, derived from the earth's motion, which it has when fixed; and that the continuation of the motion round the axis of the earth, combined with the gravitating tendency which it acquires in its descent, brings it to the bottom of the perpendicular line of the tower as correctly as if the earth, and the tower upon it, were perfectly still and immoveable. Any objection to the Copernican system, therefore, derived from this source, is of no weight.

His argument against the *annual* motion of the earth was derived from the consideration of the inappreciable *parallax* of the fixed stars. Parallax consists of an apparent change of situation assumed by any body, when we view it from a different quarter. The Danish astronomer reasoned that, if the earth moved round the sun, and consequently were, in six months' time, many millions of miles distant from the place before occupied, the fixed stars could not appear to occupy those precise points in the heavens, which they were found always to hold. This was a more startling objection than the former; and has only been set aside by modern research, which has proved the diameter of the earth's orbit to be but as a point, when compared with the vast distance of those stars, whose parallax is inappreciable.

31. Tycho Brahè was, however, the means of bringing prominently before the world the brilliant genius of Kepler, who made great advances in the astronomical wealth of that age.

Kepler finally established on an enduring basis these laws: 1st, That the planets move in ellipses, in one focus of which the sun is situated; 2nd, That if the interior of the orbit of each planet be considered as a plane, and this be divided by radii proceeding from the circumference to the sun into a number of portions or areas, these areas will bear the same proportion to one another as the times in which the planet traverses the respective arcs of the areas, or, in other words, that a planet describes equal areas in equal times; 3rd, That the squares of the mean times of revolution of any two planets are to each other, as the cubes of the greater axes of their respective ellipses; commonly enunciated thus: that the squares of the times are as the cubes of the distances. These three laws have been designated from their discoverer, "the Laws of Kepler;" and for the important results with which they are connected, do not yield to any discoveries which have been made respecting the motions of the heavenly bodies in modern times.

32. About this period we first meet with the name of Galileo; who was born at Pisa, on the River Arno, in Tuscany, A. D. 1564. He was a friend and scientific correspondent of Kepler; and with Galileo commences that era in the history of Astronomy which belongs to the use of the *Telescope.*

Galileo was a member of the first society, formed for the cultivation of Astronomy and general science. This society, named the Lyncean Society, arose in Italy in the year 1611, and existed for about twenty years. In the year 1657 arose the Accademia del Cimento, of Florence, which, under the distinguished pupils of Galileo, Viviani and Torricelli, obtained a brilliant reputation for about ten years. A royal observatory at Paris was founded soon after the latter date, and that of Greenwich in the year 1675.

We do not profess to have given either a treatise on, or a history of Astronomy, since both would be out of place here; but we have furnished a succinct account of what has been done without the telescope, so as to enable the reader to form some judgment of the benefit and assistance, which the invention of that instrument brought to the cause of Astronomical science. We shall now, therefore, take up the more especial subject of this article.

Section I. On Refracting Telescopes.

. . . . The moon, whose orb
Through optic glass the Tuscan artist views
At evening from the top of Fesole,
Or in Valdarno. to descry new lands,
Rivers, or mountains, in her spotty globe.—Milton.

. . . . Nearer we hail
Thy sunny slope, Arcetri, sung of old
For its green wine; dearer to me, to most,
As dwelt on by that great Astronomer,
Seven years a prisoner at the city-gate,
Let in but in his grave-clothes. Sacred be
His villa (justly was it called The Gem!)
Sacred the lawn, where many a cypress threw
Its length of shadow, while he watched the stars!—Rogers.

33. In order to comprehend the principles on which Telescopes* are constructed, and on which they act, it will be desirable to pursue the subject of the reflexion and refraction of light from the point at which we left it in our article on the Prism, (51,) the farther prosecution of that branch of the inquiry being more suited to the object of this paper than to that of the Prism.

We have shown, that, when a beam of light impinged in a diverging form on the surface of a globe of glass, after penetrating the anterior surface of the glass, it was refracted or bent into such directions, that the component rays of the beam were brought nearly or quite parallel to each other, according to the distance of the point of divergence; and that, when the rays emerged from the second surface, they were again deflected from their directions with respect to one another, and brought into a convergent form, by which they were collected again into a focus or point, at a distance from the sphere, which bore a certain relation to the distance of the point of divergence.

34. We must now consider the results, when the refracting body is not a *sphere*, but a *piece* of glass, spherically curved on one or both of its surfaces.

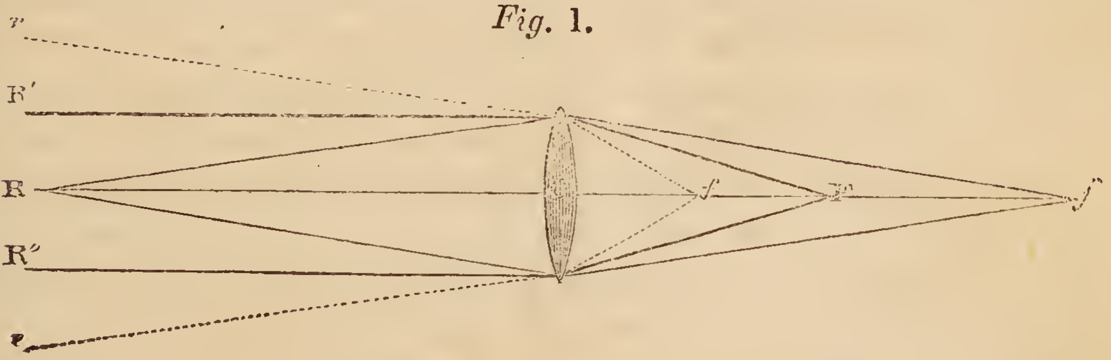
The forms of these pieces of glass, which we shall find it convenient to describe, are four: the *plano-convex* (convex on one side, and flat on the other): the *double-convex* (convex on both sides): the *plano-concave* (concave on one side, and flat on the other): and the *double-concave* (concave on both sides). Each

* This word is derived from the Greek τηλε, *afar off*, and σκοπεω, *to see.*

one of these is called by the general name of *lens* (which is the Latin for a *small flat kind of bean*). Let us now consider the passage of light through a *double-convex* lens.

35. It may easily be conceived that the resulting phenomena will be different, according as the incident rays are parallel, diverging, or converging. We will first consider *parallel* rays. If R R′ R″, (fig. 1), be parallel rays impinging on the lens, in a direction perpendicular to its length, they will be slightly converged in passing through the lens, and still more so on emerging from the second surface, insomuch that they are brought to a focus at F. If other parallel rays impinge upon the lens in a direction which is oblique to the length of the lens, they will be focalized at a point below the focus F, if they proceed from a higher station than R′ R″; but if the rays come from a lower station, they will be collected at a point above the middle focus F. In all these three cases, it will be found that there is one ray of each bundle,—viz., the *central* ray,—which is not turned

Fig. 1.



out of its direction, but proceeds straight through the lens towards the focus. The point F is called the *principal focus* of the lens; and the distance from the centre of the lens to that point, is called the *focal distance*. This distance depends for its numerical value conjointly on the curvature of the lens, and on the refractive power of the glass of which it is made; for it is plain, from what has been before stated, that, if the refractive power be increased, the bending experienced by the rays will be greater, and focalization will occur at a smaller distance from the lens; whereas, if the refractive power be diminished, the convergence will proceed more slowly, and the distance of the focus F, from the lens, will be increased. Now, it has been computed mathematically, that if the index of refraction of the lens be $1\frac{1}{2}$ or 1·5, the focal distance will bear a very simple and easily computed relation to the size of the lens; and it so happens that glass makes a very near approach to that index of refraction, as may be seen by reference to the table. (Prism, 34.) In speaking of the focal distance, therefore, we shall assume, in

all cases, that we have lenses formed of such kind of glass as will give an index of refraction equal to 1·5.

If, then, the lens be equally convex on both surfaces, the distance of the point F from the centre of the lens, or the *focal distance*, will be equal to the radius of the spherical surface of the lens, or the radius of the sphere of which we may suppose the lens to be a portion scooped out. But, if the two surfaces be unequally convex, the focal distance is thus obtained:—Multiply the radius of one surface by the radius of the other, and divide twice that product by the sum of the radii: the quotient will give the focal distance.

36. If we now suppose the rays to be in a *converging* state, when they impinge on the lens, the focal distance will obviously be diminished; because part of the converging effect, which the lens is calculated to produce, is already done before the rays impinge on the surface. If, on the other hand, the rays be in a diverging state, when they impinge upon the lens, that divergence adds to the quantity of bending which the rays must undergo before they can be converged to a focus; and, consequently, a longer time must elapse, or a longer distance must be travelled, before that focalization can be brought about. If we confine our attention to those beams, the central ray of which approaches the lens at right angles to its length, we shall be able to represent the progress of *diverging* and *converging* rays by the same figure.

Let us suppose *r r*, fig. 1, to be *converging* rays, impinging on the surface of the lens. They are farther converged on passing through the lens; and on emerging from the second surface, are again converged, so as to meet in a focus at *f*, which is nearer to the lens than if the incident rays had been parallel: the focus in the latter case being at F. But suppose now, that *diverging* rays emanate from R, and impinge upon the lens: the lens has now a greater power to contend against, than in either of the former instances, and cannot focalize the rays at a less distance than *f′*. Thus we see, that the focal distance is least for converging rays, a mean for parallel rays, and greatest for diverging rays. It likewise follows from the nature of these processes, that, in proportion as the convergence of converging rays increases, the focal distance C*f* diminishes; and, as the convergence diminishes, the focal distance increases. Also, in proportion as the divergence of diverging rays increases, the focal distance C*f′* also increases; and as the one diminishes, the other will diminish also. This law, moreover, is constant, that *the focus of converging rays is always between the lens and the prin-*

cipal focus F; and that *the focus of diverging rays is always beyond the principal focus.* The dependance of the position of the focus f' of diverging rays, upon the distance between the lens C and the point of divergence R, is thus found:—Multiply the principal focal distance C F by the distance C R, and divide the product by the difference of the same two quantities:—the quotient will give the focal distance C f'. One consequence of this law is, that, if the distance R C be double the principal focal distance C F, the focal distance C f' of diverging rays will also be double of the distance C F.

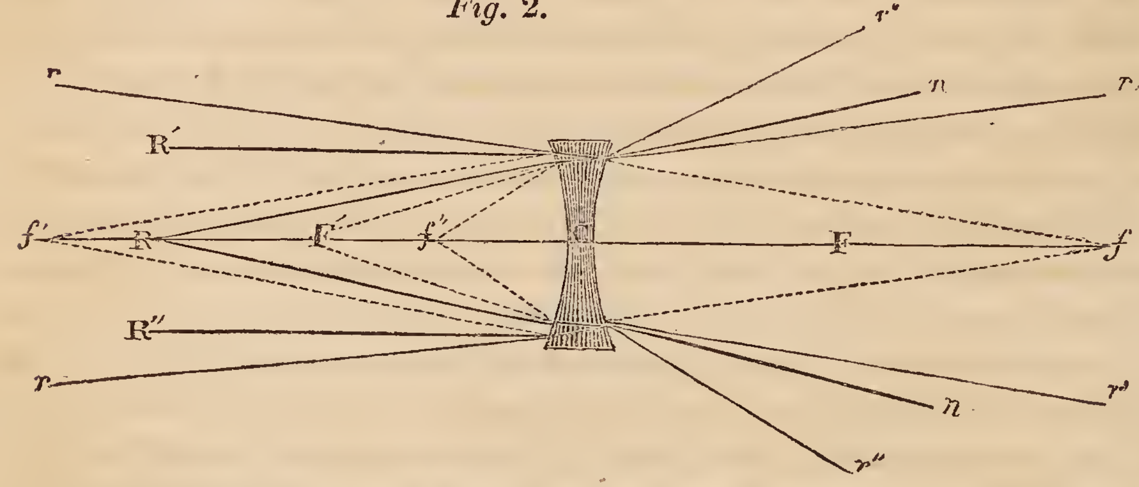
37. Now we shall be able to connect all these details very easily with the results, which would follow from the employment of a *plano-convex* lens. We know, from what has been said in the paper on the Prism, that a plane surface of glass produces no converging effect upon rays of light. We may, therefore, readily infer, (as is really the case) that, as the refractive or converging power of a plano-convex lens is only half of that of a double-convex lens, the focal distance of parallel rays passing through it, will be double of the focal distance of a double-convex lens. Accordingly, we find that the principal focal distance of a plano-convex lens is equal to the diameter of the sphere of which the lens may be considered as a segment; whereas, the principal focal distance of the double-convex lens is only equal to the radius of the same sphere. The focalization of the different kinds of rays is, in the plano-convex lens, similar to that of the double-convex, with the modification of distance just alluded to. We need not, therefore, pursue this inquiry farther.

38. We will now take the case of a *double-concave* lens, and endeavour to trace the effect, which it will produce on incident rays. We must here be prepared to give up the idea of focalization; for the rays are in all cases made more, instead of less, divergent. In order to simplify our illustration, we will only consider the progress of a bundle of rays, the path of which is at right angles to the length of the lens, premising that the same reasoning will apply to a bundle of rays, the general direction of which is oblique.

Let R R′ R″, fig. 2, be *parallel* rays incident on the anterior surface of a double-concave lens. The central ray will (as in all other cases) pass through the lens without change of direction; but the rays which enter nearer to the edges of the lens will, on penetrating the surface, be refracted away from the central ray; and on emerging from the second surface, will be refracted still more from the original direction; so that the

whole of the rays will emerge from the lens in a diverging form, towards the points *n n*. This degree of divergence is not less regulated by fixed laws, than the convergence produced by the convex lens. If we conceive the divergent rays to be produced backward from *n n* to F, where they may meet in a point, it will be found that the distance F C is equal to what the focal distance would be if the lens were of equal curvature, but *double-convex*, instead of double-concave; that is, the distance F C, is equal to the radius of curvature of the lens, supposing it to have been *double-convex.*

Fig. 2.



Let us now trace the progress of *converging* and of *diverging* rays through a similar lens.

If *converging* rays, *r r*, fall upon the lens, and have such a degree of convergence that they would, if the lens were not interposed, converge to a focus at *f*, beyond the principal focus F, they will be diverged at the two surfaces of the lens, into the direction *r′ r′*, as if they emanated from a point *f′*, in front of the lens. Now the relative positions of the two imaginary points *f* and *f′*, depend upon each other in exactly the same way as the two similar points from the *convex* lens. If, therefore, we remember that the two foci on opposite sides of the lens are *real* points when the convex lens is employed, and *imaginary* points when the lens is concave, we shall be able to apply the same calculation to the determination of the two points, whether the lens be convex or concave.

39. But, suppose the rays to be *diverging*, instead of converging, R being the point of divergence: we then find that the divergence is increased at the second surface. The directions *r″ r″*, into which they will be deflected, will be such as would seem to emanate from a point *f″*, between the principal focus F′, and the lens. Now the real point R, and the imaginary point *f″*, depend upon each other in the same way as if the lens were convex; with this difference, that, in the latter case, the two

points are on *opposite* sides of the lens, while with the concave lens, both points are on the *same* side of it.

40. The remarks applicable to the connexion between a double-convex and a plano-convex lens, refer also to the connexion between a double-concave and a plano-concave lens. The circumstance of one surface being plane, and thus exerting neither converging nor diverging power upon the lens, reduces the absolute effect to one-half of that which would result from employing a lens with both surfaces curved. We need not, therefore, extend the inquiry to the plano-concave lens. We may also state that if the lens be double-concave, but its two surfaces have different radii of curvature, the compound effect of both surfaces is determined in the same way, as if the lens were doubly, but unequally convex. (35.)

41. We are now in a condition to connect these processes of focalization with two very important phenomena; viz., the *formation of images*, and a *change in the apparent magnitudes of objects*.

If we divide a luminous surface into as many parts as we please, indeed into so many, that each part may be considered as a mere point, we shall still find that each one of these parts will send off rays to ever point of an object presented to it; so that the light received from any luminous body, is not to be considered as a whole, and coming from the entire surface, but as a part, and made up of a great number of bundles of rays—one bundle proceeding from every distinct point of the luminous body. Suppose, therefore, that we could divide the surface which the sun presents to us, into 1000 different parts, each of which would appear small to the eye, and that we were to divide the surface of a sheet of paper, on which the sun is shining, also into 1000 parts. Then, each point of the sun's surface, supposing that none of his rays be absorbed in their passage to the earth, would send rays to each of the divisions of the paper, making 1000 in all; and as we suppose there are 1000 such points on the luminous surface, each one possessing the same properties as the others, we find that there are in all 1000 times 1000, or 1,000,000 of rays emitted from the sun to the sheet of paper. If, then, this be the case, when we limit the number of divisions to 1000 on each surface, what must be the number, when we consider that there as many such points as there are rays from the sun's surface? The number, of course, is beyond our conception; and we can only fix our ideas by saying, that from every physical point of the luminous surface, there proceed rays to every physical point of the illuminated surface.

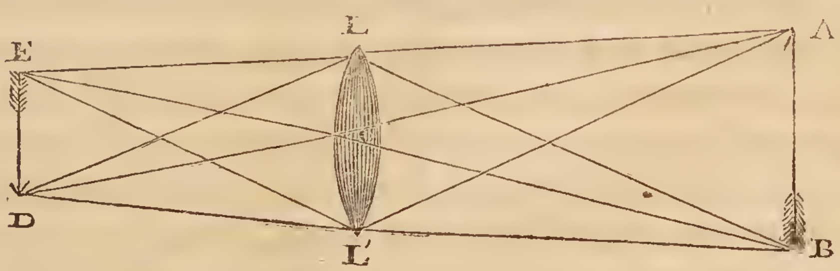
42. This being premised, we must now draw the attention of the reader, to a definition, on which the clear understanding of much of what follows, will depend. Let us direct our attention to one single point of the luminous surface, without attempting to fix the size of that point: then, all the light which emanates from that point, is termed a *pencil of light*, which pencil consists of an incalculable number of rays, impinging on every part of the surface of a body. When, therefore, in our following details, we use the three terms *parallel*, *diverging*, and *converging*, we must be understood to allude always to rays belonging to *one pencil*, and therefore proceeding from one point of an object. From our definition of a *pencil of rays*, it would seem that rays must be divergent, as they proceed from the luminous body; and that they cannot be either convergent or parallel. This is strictly the case, so long as the rays are allowed to follow their original directions; and we shall find that, whenever we have to deal with rays of one pencil which are really parallel, or really convergent, they have been made so by the media through which they have passed.

43. This is strictly true; but there are cases in which a slight deviation from its rigour is admissible. Let us consider a point on the sun's surface, and a pencil of light emanating from that point, some of the rays of which pencil fall on the surface of a lens one inch in diameter. Now, if we reflect a little, we shall see that the rays of that pencil are really diverging, or that they form a *cone* of rays, the apex of which is the point in question, and the base is the surface of the lens. But although it be strictly true that these rays diverge from one another, yet the divergence is so extremely small, that we shall scarcely be in error, if we call them parallel. The length of the cone is about 95,000,000 miles, while the base of the cone is only one inch; a disproportion which no instruments would make manifest. We shall, therefore, in future, consider all the rays of any one pencil of light emanating from the sun, to be *parallel*, without at all inquiring how many rays constitute a pencil, or how many pencils emanate from the surface of the sun. For terrestrial objects, however, it is not so difficult to determine that the rays of any given pencil really *diverge* from one another.

44. This being understood, let us now suppose that we have an object, which may be represented by A B, fig. 3, and that this object is placed before, and at some distance from, a double-convex lens, L L′. A pencil of rays will proceed from the point A of the object; another pencil from B, and others from every intermediate point between A and B. We will consider

only the two extreme pencils, in order to avoid confusion in our ideas of the figure. A L, A C, A L′, are three rays of the pencil proceeding from A: which three rays fall upon the surface of the lens, and pass through it, the central ray A C proceeding direct in its path, and the other two being bent or refracted, so as to meet in a focus at D. D, then, is the focus of those three rays; and, as the intermediate rays are focalized to the same point, we find that D is the focus of all the rays of the pencil coming from A, and that whatever object A may be (such as the point of an arrow) an image of a similar object is formed at D. Precisely the same thing occurs with the rays of a pencil springing from B; except that their point of focalization is E instead of D; and, if we were to trace the progress of pencils proceeding from every point of this object between A and B, we should find that they would all have points of focalization between D and E. There would be, in fact, an aërial image of the object, formed at and between D and E, the proportions of the different parts of which image would be the same as in the original object itself; but whether the actual size of the aërial image would be the same as that of the object, would depend on other considerations, which we must now explain.

Fig. 3.



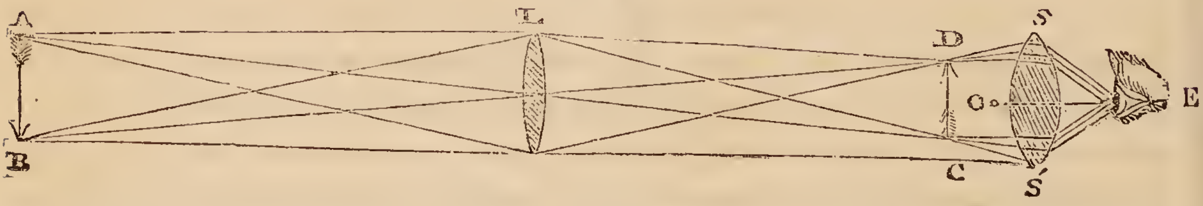
45. By referring back to Par. 36, we see that, in order that diverging rays may be converged to a focus, by a double-convex lens, at a distance from the lens equal to the distance of the point of divergence,—the latter must be double the principal focal distance of the lens. If, for instance in our present figure, the principal focal distance of the double-convex lens were one inch, the distance of the point A from the lens, in order to obtain the effects which we are considering, would be two inches. In such a case, therefore, the point D would likewise be two inches from the lens. The same relation would exist between the distances of the points B and E, from the lens; and one consequence of that relation would be, that the aërial image E D would be exactly the same size as the object A B; a circumstance which would not occur under any other adjustment of the distances. In our figure we have supposed the distance C A to be more

than double the principal focal distance: from which it follows, that the distance C D is less than double the principal focal distance: hence the image E D is *smaller* than the object A B. If, however E D had been the object, then A B would have been the image; and this image would have appeared *magnified* by the lens.

The same train of effects would follow the employment of a *plano-convex* lens, instead of the double-convex; with the exception of that modification of focal distance which we have before explained (37). As an image, properly so called, can hardly be produced by a *concave* lens, we need not extend the inquiry to lenses of that form.

46. The formation of an aërial image leads to results of a most curious kind, into which we must now enter. The reader must be prepared to understand that the image, thus formed, may be viewed by the eye as if it were the *object* itself; and the magnifying power of a convex lens derives much of its value from this source. We must use a figure to illustrate this:—Let us suppose that we have a double-convex lens L, fig. 4*, and an object before it, of which object an image C D is formed at the same distance on the other side of the lens; that is to say, the distance A L is double of the principal focal distance of the lens;—by which the object A B, and the image C D, are of the same dimensions; and let us further suppose that an eye

Fig. 4.



is placed at *o*, a short distance behind C D. Now, the principal test by which the mind judges of dimensions, is the *apparent angle* under which we view a body. A thimble may appear as large as Salisbury Cathedral, by being brought sufficiently near to the eye; and it might seem to the mind to be fully as large, were there not other tests by which such an erroneous impression is corrected. Now, to apply this to our figure:—If the lens were not present, the eye would see the object A B, under the angle A *o* B, or it will appear of that size; but the interposition of the lens actually prevents the eye from seeing the *object*, and the eye sees only the image C D instead. On entering upon this study, it must appear a most extraordinary thing, but it is not

* In this figure, the letters S S′ E, relate to the subsequent illustration. (48.)

the less true, that the eye, under such circumstances, does not view the real object A B, but only an *image* of it. Now, the angle under which that image is viewed, is the angle C *o* D, which is obviously much larger than the angle A *o* B; the consequence of which is, that that phenomenon is produced which we call *magnifying*. Instead of viewing an object from a distance, we view an image or representation of that object, (of the same size) from a smaller distance, and thus does it appear larger:—just as a shilling, which, hardly seen at ten yards' distance, seems of a good size, when brought nearer. To ascertain how much magnifying power we have gained by viewing the image instead of the object, we may draw lines from *o*, through the points C D, to meet the line A B, produced, and we shall thus see how large the object A B must be in order to appear, without the intervention of the lens, as large as the image C D. That length, compared with the length A B, would give the amount of elongation produced; and as the transverse or diametrical enlargement is in the same ratio, if we square the increase of length, we obtain the magnifying power for the whole area or surface of the object.

47. These results, it will be perceived, are obtained, when the object and the image are in reality of the same size. If, therefore, the adjustment of the distances be such as to make the image larger than the object, the magnifying power of the lens is still greater than in the former instance. But, if the distance of the object from the lens be more than double of the principal focal distance of the lens, the image will be smaller than the object, and the total magnifying power will be somewhat diminished. The amount of this increase or decrease of size,—so far as the comparison between the size of the object and of the image is concerned,—may be determined from this law:—*As the distance of the object from the lens : the distance of the image from the lens : : the size of the object : the size of the image.* If, therefore, the former distance be double the latter, the size of the object will be double the size of the image.

48. In addition, however, to the increase of the apparent dimensions of an object, when we view the image instead of the object itself, we have now to speak of a farther enlargement, by intercepting the rays from the image of the eye, by means of another lens, so as to increase the angle under which we see the image.

Suppose that D C, fig. 4, is the image produced by the focalization of rays through a double-convex lens, which may be conceived to be at the left of the figure, as at L. The eye E would

see that image under the angle D E C, which would, therefore, appear larger than the object, because we suppose the latter to be at some distance to the left of the lens. Instead now of allowing the rays to enter the eye from the image, as in the former case, let us suppose that another double-convex lens S S′, is interposed between the image C D, and the eye E. The rays of the pencil from the point D, slightly diverge on leaving their point of focalization, and approach the lens in that manner: but here they are retarded in the process of divergence, and brought nearer to parallelism. On emerging from the second surface, they are brought into absolute parallelism, and in that condition enter the eye. We must again beg the reader to attend carefully to the meaning of the term, *pencil* of rays: we do not say that all the rays which now pass through the lens *are* parallel to one another, but that all the rays which compose any one pencil, are *brought into* parallelism:—thus, a pencil proceeds from the point D, another from the point C, and others from the intermediate parts of the image; and all the rays composing any one of these pencils, become parallel to each other by the refracting effect of the lens. But, although the rays of each pencil are parallel, yet the different pencils are not parallel. The pencil from the edge S of the lens, proceeds obliquely downwards, while that from the edge S′ proceeds obliquely upwards; and the intermediate pencils, not given in the figure, proceed in corresponding directions. In order that the rays of any one pencil should be thus parallelized, it is necessary, as has been before shown, that the image C D should be in the focus of the lens, or that the distance D S should be the principal focal distance of the lens.

Now, if we look at the angle which the extreme pencils make with each other at the eye, we shall perceive that it is greater with respect to the lens than with respect to the image; or, that the angle S E S′, is greater than the angle D E C; and thus the image appears larger when the lens is interposed between it and the eye, than when no such lens is present. The reason why the angle of approach is greater when the lens is interposed, is, that we are enabled to hold the eye as close as we please to the image, by having a lens of sufficiently short focus. Lenses have been made, by exquisite methods of workmanship, with a focal length not exceeding the hundredth part of an inch; and whether the focal length be that minute quantity, or as much as a hundred inches, there is still this property remaining constant: that, *if an object be placed in the focus, the rays of each pencil from that object will be brought parallel to one*

another by the time they emerge from the lens. Now, an object of twelve inches' distance, appears only one-twelfth as long as the same object when only one inch distant. If, therefore, we be accustomed to view the image, without the lens, at a distance of six inches, and be enabled, by the use of the lens, to see the same object at one inch distance, we magnify its length six times, or its area the square of six, or thirty-six times: and so on for any other focal length.

49. Thus, then, we see that there are three modes in which the apparent magnitude of an object can be increased; 1st, By placing a convex lens before it, at a distance less than double the focal length of the lens; by which an image, larger than the object, is formed on the other side of the lens. 2nd, By placing the eye at a short distance, say six inches, behind this lens, we may see the image under a much larger angle than the object would subtend, on account of the greater distance of the latter. 3rd, By placing a convex lens, of very small focal length, between this image and the eye, we can still further increase the apparent magnitude of the image by being enabled to view the image at half an inch or an inch distance, instead of five or six inches, which is the smallest distance at which objects can be viewed under ordinary circumstances.

50. It is a beautiful law in science that "action and reaction are always equal;" and although we are not in the habit of applying that law to optical phenomena, yet we may illustrate its operation, in this way: that the power, which is gained by making an object appear larger than it really is, has an antagonist-power in the circumstance that the quantity of the object, which we can see at one time, is proportionably less than before. If we did not apply our second lens *close* to the eye, we should be able to see a larger portion of the object than is visible when the lens is interposed. It is, therefore, by a sacrifice of one convenience that we gain another; and we are, in practice, often willing to give up an extensive view of an object, in order to obtain a distinct view of some portion of it. We can make 1 pound of water raise 10 pounds, by means of the hydraulic press, if we be willing to give 10 inches of motion to the former, in order to obtain 1 inch in the latter; or, we may lift 100 pounds by a lever with a force of 10 pounds, if we be prepared to give 10 times as much range of motion as we receive. We are generally able to detect the operation of some such principle of compensation, whenever we obtain an increase of power; and it is always instructive to notice such cases.

These introductory remarks on the magnifying power of

lenses, and on the formation of images by their means, will prepare us for what is to follow.

51. It appears, from the best construction which can be put upon conflicting evidence, that in the year 1609 two spectacle-makers, by names Zacharias Jansen, and Henry Lipperhey, lived near each other in the town of Middleburgh in Germany, and that both of them claimed the honour of the discovery of the Telescope. It has been conjectured, however, that Jansen accidentally noticed such a combination of two lenses as would make a Telescope; while Lipperhey, equally by accident, hit upon a microscopic form of the lenses. In Jansen's shop was exhibited the little instrument which became the germ of future discoveries: on looking through it, the weather-cock on a neighbouring church was seen to be both *magnified* and *inverted.* Curiosity was excited, but no one knew the principle which produced the phenomenon. From that shop it was purchased by the Marquis Spinola, who presented it to one of the archdukes of Austria.

It appears, however, that many conjectures concerning the probable effect of a combination of lenses, had been made long before that period. Indeed, Roger Bacon, who lived 300 years before, made the following remarks:—"The greatest things may be made to appear exceeding small, and on the contrary; the most remote objects also may appear just at hand, and on the contrary. For we can give such figures to transparent bodies, and dispose them in such order with respect to the eye and the objects, that the rays shall be refracted and bent towards any place we please, so that we shall see the objects near at hand, or at a distance, under any angle we please. And thus from an incredible distance we may read the smallest letters, and may number the smallest particles of dust or sand, by reason of the greatness of the angle under which we may see them. And on the contrary, we may not be able to see the greatest bodies just by us, by reason of the smallness of the angle under which they may appear. Thus a boy may appear to be a giant, and a man as big as a mountain, forasmuch as we may see the man under as great an angle as the mountain, and as near as we please; and, thus a small army may appear a very great one, and, though very far off, yet very near us; and on the contrary. Thus also the sun, moon, and stars, may be made to descend hither in appearance, and to appear over the heads of our enemies; and many things of the like sort, which would astonish unskilful persons."—BACON'S *Opus Majus.*

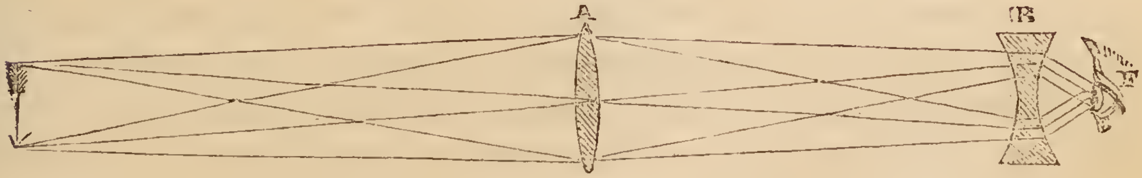
It certainly seems difficult to conceive that Roger Bacon

could have written such a passage as this, without having seen the telescope, unless, indeed, he had accidentally placed two convex spectacle-glasses between his eye and an object, in the manner which we have described. There is, however, no proof that such an instrument as the telescope had been constructed before the time of Jansen: we shall therefore proceed with our details.

52. Galileo shortly after gained the knowledge of the construction of the wonder-exciting instrument, made at Middleburgh, and immediately set about constructing one for himself. He fitted two lenses, one convex, and the other concave, into an organ-pipe, with such an adjustment of the two lenses, that the length of the interval between them was equal to the difference of their focal lengths: thus he formed the first real Telescope,—the principle of the construction of which has obtained for it the name of the "Galilean Telescope."

It consists of a convex lens, A, (fig. 5,) nearest to the object; and a concave lens, B, near the eye: the focal length of the convex lens is A F, and that of the concave lens is B F; so that the foci of both coincide at the point, F. Now, the effect of

Fig. 5.



that coincidence is to convert the converging rays, as they impinge on the concave lens, into parallel or nearly parallel rays; that being the condition under which the eye can best see them: that is, all the rays of the pencil, proceeding from the upper point of the object, emerge from the concave lens parallel to each other, and pointing downwards; while all the rays of the pencil proceeding from the bottom of the object, become parallel, and are directed upwards. The effect of a concave lens, used in this manner, we have not yet explained; it is this: If the concave lens were not present, an image of the object would be formed in the focus, F, of the convex lens, but the interposition of the concave lens converts the converging rays into *parallel* rays: that is, the rays of any one pencil become parallel to each other. It is in such a state, that rays are calculated to produce distinct vision in the eye; or when, at least, they are in a position not deviating much from parallelism. The vision is therefore correct; but at the same time the image

becomes magnified, from the circumstance that the different pencils are more widely diverged from one another, and thus make the object appear under a larger angle. Thus two changes are effected through the concave lens: 1st, the rays of each pencil are brought nearly into parallelism, and thus into a fit state for vision; and 2nd, the different pencils having become more widely separated give a magnified image. This is the principle of the *Galilean Telescope*, and of the modern *opera-glass.* In the latter, slides are arranged, so that we may lengthen the tube, and consequently the distance between the lenses, according as the object to be viewed is *far*, or *near;* for we have seen, that, as the object recedes from a convex lens, the focus approaches nearer to the lens.

53. This, then, was the first attempt of Galileo at telescope-making, an occupation followed by persecutions which make us blush for human nature. The telescope magnified three times, and he carried it to Venice, where it attracted the most extraordinary attention: Galileo's time, for more than a month, was employed in showing and explaining its nature to the principal inhabitants of Venice: and at the end of that period, Leonardi Donati, the doge of Venice, requested it as a gift, and rewarded Galileo with a salary of a thousand florins a year. Another Venetian, Sirturi, a friend of Galileo, relates a ludicrous instance of the insatiable telescopic-mania which had seized on the people. He went one day to the tower of St. Mark, in order to make observations on its summit, but the people espied him, and compelled him to hand a telescope which he had made for himself, from one to another, until all had gratified their curiosity by having a peep; and after he had been detained several hours, he was not a little glad to regain his telescope and return home. But this was not all: he heard them inquiring at what inn he lodged; and foreseeing the inconvenience of the celebrity which was beginning to attach to him, he left Venice early the next morning, to pursue his observations with greater privacy.

54. Galileo then made another telescope of a better construction than the former, and which magnified eighteen times. With this instrument he explored the heavens, and was not long before he perceived three small stars near the body of Jupiter; so small, indeed, that, not being visible to the naked eye, they had escaped the notice of previous observers. On an evening or two afterwards, he was surprised to see that they had changed their places relatively to each other, and shortly afterwards that they were joined by a fourth: and the result of

many nights' observation convinced him that they were *satellites*, or *moons*, revolving about the body of the planet Jupiter.

This important discovery produced a great sensation among the influential men of those times. Cosmo de Medici, Kepler, and a few other men of enlightened minds, appreciated its importance; but a larger number either doubted the fact, or called it a presumption to talk of discovering new bodies in the heavens. Kepler, in a letter to Galileo, says, "Wachenfels stopped his carriage at my door to tell me;" (of the discovery of the telescope) "when such a fit of wonder seized me, at a report which seemed so very absurd, and I was thrown into such agitation at seeing an old dispute between us decided in this way, that between his joy, my colouring, and the laughter of both, confounded as we were by such a novelty, we were hardly capable, he of speaking, or I of listening." But some of Galileo's cotemporaries viewed it in a very different light from Kepler. Galileo said to Kepler in one of his letters,—"Oh, my dear Kepler, how I wish that we could have one hearty laugh together. Here, at Padua, is the principal professor of philosophy, whom I have repeatedly and earnestly requested to look at the moon and planets through my glass, which he pertinaciously refuses to do. Why are you not here? What shouts of laughter we should have at this glorious folly! And to hear the professor of philosophy, at Pisa, labouring before the grand duke with logical arguments, as if with magical incantations, to charm the new planets out of the skies."

55. With the aid of his telescope, Galileo discovered many important phenomena connected with the heavens, besides the satellites of Jupiter. He obtained decisive proof that the moon was not only an opaque body, but was also covered with elevations and indentations of surface, just as is the case with the earth. He likewise determined the wonderful truth that the *milky way*, which most of our readers have doubtless seen, is an assemblage of minute stars, so thickly congregated that they appear to the naked eye, as nothing more than a broad stream of faint light in the firmament, which has obtained for it the name by which it is generally known. He likewise was the first to make definite observations on the spots on the sun's disc.

56. But it is melancholy to relate, that these brilliant disclosures brought temporary disgrace and positive suffering upon their author. Galileo, at the age of seventy, after having devoted his life to useful and valuable labours, was forced to abjure his philosophical opinions; and to declare, on his knees, that he believed his doctrines concerning the motion of the earth round

the sun, the existence of solar spots, &c., to be false and pernicious. The moral firmness of the old man was not sufficient to make him brave the terrors of the Inquisition, and we must therefore look with a lenient eye at this abjuration of doctrines which at the very moment he firmly believed to be true: but what shall we say of those men who, under the plea of religion, could subject so noble a mind to such humiliating degradation!

57. When the telescope, as used by Galileo, became generally known, it began to be thought that the mode of focalizing the rays produced a smaller magnifying power than might be produced by a different arrangement; and a telescope which, from the purposes to which it has been applied, is called the *Astronomical telescope*, was constructed a few years afterwards. It consists of two double-convex lenses, L and S S′, fig. 4, placed at a distance from each other equal to the sum of their foci: that is, the focal distance of the lens L is L D, and that of S is S D. This is the position of the lenses for *parallel* rays, that is, those which come from an immense distance, such as from the heavenly bodies. The reader must therefore conceive the object A B, to be at a great distance on the left, so that the rays of a pencil from any one point, may be conceived to be sensibly parallel to one another. Such a pencil, proceeding from the upper part of the object, (as A,) will be focalized at the lower part of the image, (as C,) which is just such a point, that when those same rays again cross each other, and diverge towards the lens S S′, they will, on leaving the other side of that lens, be again parallel to each other, and consequently in a fit condition for producing distinct vision. That condition being thus attained, we have now to determine what is the amount of advantage gained by the instrument, or, what is the magnifying power. This is known by dividing the focal length of the object-glass, by the focal length of the eye-glass; that is, if the distance L D, be 4, and the distance S D, be 1, then will the magnifying power equal 4: or, if L D be 20, and S D be 2, then it will be 10. Consequently, the greater the disproportion between the focal lengths of the lenses, the greater will be, *cæteris paribus*, the magnifying power. But this law has a limit, in the impossibility of obtaining clear vision, when the lenses are very disproportionate in power.

58. In looking at the heavenly bodies, it is not of much consequence whether we see them in their erect position, or inverted; consequently, the inversion of position, which is produced by the Astronomical telescope, is not actually a defect. But, when such an instrument is used for land-purposes, such as

to view a distant landscape, &c., we should be not a little perplexed in our observation, if we were to see a church resting on its steeple-top, and men and cattle with their heads downwards: to remedy this defect, therefore, it is necessary to insert two more convex lenses between the former two, which must consequently be removed farther from each other. Thus the pencil of rays proceeding from the bottom of the object *a*, fig. 6, pass

Fig. 6.

through the lens A, and are converged to a focus at the top of *b*, from whence, passing through the lens B, they are then fitted for distinct vision, by being parallelized on the right of B. But in order to reverse the position of the image, as thus formed, the parallel rays are suffered to pass on to another lens C, of equal focal power with B. Now, as diverging rays from the point *b*, were made parallel by passing through the lens B, so conversely, parallel rays are changed into converging rays by the lens C, and the focus *c* is as far from C as is the focus *b* from B. We have, therefore, another image, c, formed in the erect position, and the converging rays proceeding from that image to a fourth lens, D, are by it converted once more into parallel rays, and enter the eye in a fitting direction to give an exact view of the object. It is an essential part of this arrangement that the point *c* should be the focus of both the lenses C and D, and that *b* should be the focus of both A and B. B C and D are always of the same focal length or focal power: but A has a longer focal distance; otherwise no magnifying power would be obtained.

This arrangement is attended, then, with three desired results. 1st. Distinct vision is obtained. 2nd. The objects are magnified. 3rd. They are represented in their *erect* or *natural* position. But these advantages, as in every other case, have their limit; every imperfection in the lenses, whether of material or of form, is increased by the repeated refractions, and much light is lost by having to pass through four thicknesses of glass.

59. These two telescopes, (which, because the light is refracted through lenses, are called *Refracting Telescopes*,) have received various improvements from time to time, but the principles upon which their action depends, are, in all cases, nearly what we have shown above: an image is formed in some part of the tube of the telescope, by the focalization of the rays which

have proceeded through the object-glass; and another lens is placed at such a distance from that image, that rays diverging from the image shall, after refraction through that lens, (called the eye-lens,) enter the eye parallel to each other. It must be remembered that by *parallel* we do not mean that all the rays *are* parallel to one another, for that would produce no object at all on the retina; but that all the rays of any one pencil are *brought into* parallelism, and thus become focalized to a point on the retina.

60. Compound eye-pieces, and various other niceties of construction, which rank among the most exquisite specimens of mechanism, have been from time to time proposed and employed, to give greater perfection to the image received by the eye; but the principle of their action is not very different from what has already engaged our attention. There is one modification, however, which it is necessary for us to advert to; which is, the means of lengthening or shortening the distance between the object-glass and the eye-glass, by making the tube of the telescope to consist of several pieces, sliding one within another. We have just stated that rays coming from a great distance may be considered as very nearly parallel; and, in the theory of the telescope, it is assumed that the rays which enter it are parallel. But when we view an object at an appreciable distance, (say any object on land,) the rays then really diverge on approaching the object-glass; and the consequence of that divergence is, that their subsequent convergence is delayed, so that the focal point for those rays, which had approached the object-glass in a divergent form, is farther from that glass than if the rays had been parallel; and the nearer the object is, the greater is the divergence of the rays proceeding from it to the object-glass, and the greater is the distance of the focal point of those rays on the other side of the glass. By having the object-glass, therefore, fitted into one tube, and the eye-glass fitted into another, and having the tubes so constructed that one will slide within the other, we can adjust the distance of the two lenses from each other, so as to produce foci suited to different eyes.

61. The most magnificent refracting telescope ever constructed, is one made by Fraunhofer, of Munich, for the University of Dorpat, of which Professor Struve is at the head. The aperture of this instrument is 9 French inches, (about 9·43 English inches,) and its principal focal length is about 14 feet. It is capable of magnifying to the extent of about 700 times, which, in favourable weather, presents the object with the utmost precision. Professor Struve sent a description of this

splendid instrument to the Royal Society of London: in which he says: "This master-piece was sold to us by Privy Counsellor Von Utzchneider, the chief of the optical establishment at Munich, for 10,500 florins (about £950 sterling), a price which only covers the expenses which the establishment incurred in making it. This generosity, this sacrifice to science, deserves every praise, especially as the professor and academician Chevalier Fraunhofer has offered to contribute also, in future, towards perfecting this splendid master-piece of art." The whole weight of the telescope is supported at one point, which is the centre of gravity; and although the weight is about 24 cwts, yet it may be turned in any direction with the greatest facility,—the finger being sufficient to effect the necessary motion.

SECTION II. ON REFLECTING TELESCOPES.

Delighted Herschel with reflected light
Pursues his radiant journey through the night;
Detects new guards, that roll their orbs afar
In lucid ringlets round the Georgian star.—DARWIN.

62. WE have now to treat of a different class of telescopes, which have received, perhaps, more attention than those which we have been describing;—we mean *reflecting telescopes*. In order to understand the principles on which they act, it will be necessary to take up the subject of the reflexion of light, from the point at which we left it in the article on the Prism (24).

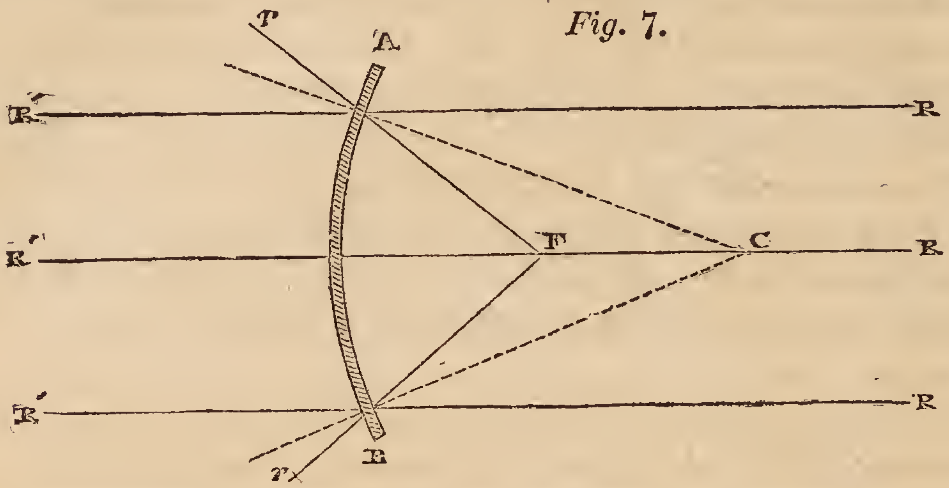
The reader will recollect, that it was shown, that, when a ray of light impinges on the surface of a *plane* mirror, it is reflected according to the law of equal angles: and that the size of the reflected image is the same as the object would appear to present, if the glass were transparent, and the candle or other object viewed were as far *behind* the glass as we suppose it to be in *front* of the glass. It was also seen that, if the mirror be *concave*, the reflected image appears larger; and that, if the mirror be *convex*, smaller, than when the glass presents a plane surface.

63. We must now, however, show that, if the mirror be *concave*, an actual aërial image is formed in front of the mirror, as perfect as that which results from refraction through a convex lens: while, on the other hand, a *convex* mirror resembles a concave lens in never being employed for the formation of images.

Let us suppose A B, fig. 7, to be a concave mirror, and R R R to be parallel rays falling from right to left upon it:—they will

be reflected in such a manner as to meet at F. Now, if we suppose C to be the centre of the sphere of which the mirror is a portion of the surface, then the point F will be half-way between C and the mirror; and all the rays R R R will be converged to a focus at that point.

Fig. 7.



64. But suppose now that A B is a convex mirror, and that parallel rays R′ R′ R′ impinge upon it from left to right:—those rays will be reflected from its surface into the directions *r r*, as if they sprang from a point F behind the mirror. It is thus customary to say that F is the real focus for parallel rays, if the mirror be concave; and the virtual focus, if the mirror be convex.

By the same figure it will be easily understood that, if rays emanate from the point F and impinge upon the concave mirror, they will be reflected into the parallel rays R R R. If the mirror be convex, and rays approach it in the direction *r r*, they will also be reflected into parallel rays R′ R′ R′.

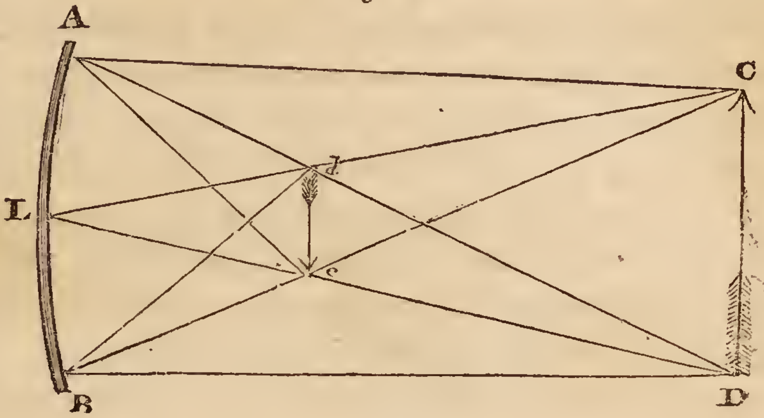
Now it will be seen, on a little consideration, that, if diverging rays impinge on the concave mirror, they will, after reflexion, be either diverging, parallel, or converging, according as the point of divergence is within, coincident with, or exterior to, the point F:—Also, that converging rays, incident on the same surface, will in every case be brought to a focus between the point F and the mirror.

With respect to the convex mirror, it follows from the law of the equal angles, that if diverging rays fall on that surface they will be reflected into paths still more oblique than the rays *r r*. If the incident rays be converging, the reflected rays will be converging, parallel, or diverging, according as the rapidity of the incident convergence is greater than, equal to, or less than, that of the rays *r r*.

65. We must now apply these properties to the formation

of images by reflexion. Suppose A B, fig. 8, to be a concave mirror, as before, and C D to represent an object placed before the mirror. A pencil of rays C A, C L, C B, proceeds from the point C, and a similar pencil from the point D. The former of these two pencils, after reflexion, focalizes at the point *c*; while the rays of the other pencil focalize at the point *d*. Similar pencils of light emanate from every point of the object C D, and focalize in intermediate points of *c d*; and thus an image is formed at *c d*, precisely the same in character as was produced by the refraction of light through a convex lens.

Fig. 8.



Now the relative distances of the object and image from the mirror, depend altogether on the distance C A with respect to the radius of the concavity of the mirror. If the rays of each pencil were parallel, or if the distance C A were infinite, then the image would be formed at a point midway between the mirror and the centre of its curvature. If the object were at a sensible distance, the rays of the pencil would sensibly diverge, in their approach to the mirror, and the image would be somewhat farther removed from the mirror than *c d*. If the rays diverged from the centre of curvature, they would converge to the same point exactly, and the image would coincide with the object and be equal to it in size. If the point of divergence be within the centre of curvature, the image will be beyond that centre, and will be larger than the object. The image thus formed, whether or not equal in size to the object, is always well defined; and may be seen suspended as it were, in the air, if we cause a thin blue smoke to pass up to it from a chafing-dish, or other vessel placed beneath.

As convex mirrors are never employed to converge rays to a focus, we need not here extend our inquiry respecting them: except so far as to remark that the principal optical purpose to which they are applied, is to convert diverging into either parallel, or converging rays.

By the application of these properties of light, reflected from a convex or concave surface, we shall be able now to understand

the principle, on which the reflecting telescope has been, and still is, constructed.

66. Sir Isaac Newton, whose brilliant fortune it was to improve almost every subject to which he directed his gigantic mind, was the first to put in practice the idea of employing reflected light for the formation of the image in a telescope. Vast and splendid as were the theoretical and mathematical powers of his mind, yet he did not disdain to construct with his own hands the instrument, which inductive reasoning told him would serve the purpose of a telescope.* He made the first reflecting telescope, which the world ever saw, and which is now in the museum of the Royal Society of London:—a precious memento of the ingenuity of one whose name will never die.

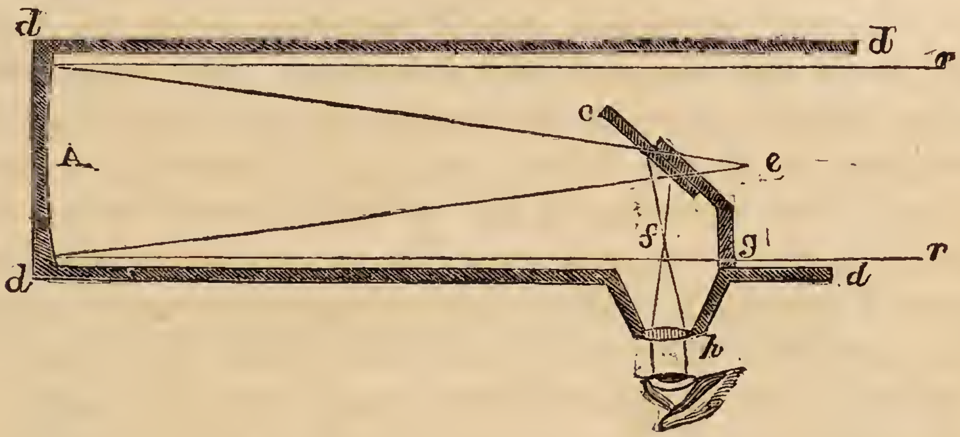
Newton's first telescope was $6\frac{1}{4}$ inches long, and had an aperture of about $1\frac{1}{3}$ inches. The eye-glass inserted in the side of the tube was one-sixth of an inch deep. The instrument, although so small, magnified 35 times, and enabled Newton to see the crescent-form of Venus, and Jupiter's satellites. He then made another, which was $2\frac{1}{3}$ inches in diameter, and therefore gave a larger reflecting surface to the speculum at the bottom of the tube.

67. Reflecting telescopes are of five specifically different constructions, and go by the names of the Newtonian, the Gregorian, the Cassegrainian, Brewster's, and Herschel's. The circumstances in which they differ one from another, are chiefly in the manner in which the image of an object is conveyed to the eye of an observer. In every instance, rays of light from a distant object pass into the tube of the telescope, (which is *open* at the end *nearest* to the object) and impinge upon the surface of a *concave* speculum at the *bottom* of the tube. These rays, after reflexion from such surface, meet again in a focus near the upper end of the tube, and there form a small image of the object; which image is conveyed to the eye of the observer by one of the five different contrivances, which form, in fact, the points of difference between the various reflecting telescopes. From this description it will be seen, that fig. 7 will give a general view of the mode in which an image is formed in the tube of a reflecting telescope. In that figure the rays are supposed to emanate from an object at an appreciable distance, and are therefore represented as *diverging* rays:—if, however, we conceive them to be *parallel* rays, such as those emanating from the sun, we should have the image a little nearer to the speculum than is represented in that figure. If this be well understood, we shall see at once the *general* principle of each of the different

reflecting telescopes; and the peculiarities of each will soon be readily appreciated. The Newtonian and Gregorian will be the two, with which we shall find it most convenient to commence our illustrations, as being the most original.

68. The construction of the Newtonian reflecting telescope we will now proceed to describe. A, fig. 9, is the *speculum*, or

Fig. 9.



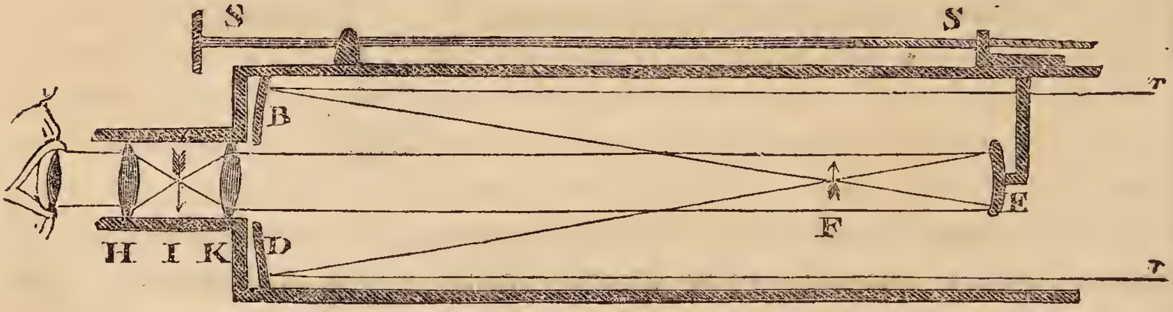
reflecting surface, formed of polished metal, either spherically, or parabolically curved:—the latter being more correct, but the former being more easy of construction. This speculum is placed at the end of the tube *d d d d*, and has such a degree of curvature, that parallel rays *r d*, *r d*, will, after reflexion, be converged to a focus at *e* near the mouth of the tube. But, before they reach this point, their progress is arrested by a plane mirror *c* so placed as to make an angle of 45° both with the length, and with the diameter, of the tube. This plane mirror is held in its place by an arm or bracket *g* fitted to the side of the tube, but at the same time capable of sliding along it, in order that the distance between the two reflectors may be increased or decreased at pleasure. Let us now suppose that *parallel* rays are entering the tube, and that they are reflected from the surface of the speculum: they are then reflected a second time, from the small plane mirror *c*; and, shortly after, cross each other at the point *f*; at which point of intersection an image of the object is formed. At this point of the process occurs an adaptation similar to what we have before described; viz., a convex lens is fitted into a socket *h*, the focal power of which lens is such that the image is in that focus; by which the diverging rays are rendered parallel before they enter the eye; and hence the magnitude of the image is increased.

This was Newton's contrivance, the power of which is estimated by the relative focal distances of the concave mirror and of the convex lens, in the following way: as the focal distance

of the eye-lens is to that of the concave mirror, so is the size of the object, as seen by the naked eye, to the size as seen by means of the telescope.

This arrangement has, however, this disadvantage, that the observer looks into the *side* of the tube. This was obviated by a new construction by Dr. Gregory, a few years afterwards, who thought that a little sacrifice of light might be made, in order to gain a more natural position for viewing the object. He therefore perforated the middle of the large concave speculum, and brought back the rays, reflected from that surface, by means of a further reflexion from another concave mirror at the other end of the tube.

Fig. 10.



69. B D, fig. 10, is a concave reflector, with a hole in its centre. E is another reflector, generally of an elliptical curvature, placed in the axis of the larger one, at a distance from it a little more than the sum of their focal distances. H K are the two eye-lenses (two being attended with some advantage), sliding in a tube fixed behind the large mirror. The distance of the small mirror from the larger one is regulated by a screw S S attached to the arm, which holds the small mirror. Now, if *r r* be nearly *parallel* rays, proceeding from a distant object, those rays will, after reflexion from the large mirror, be conveyed to a focus at F, where an image will be formed. They then again diverge, and are again reflected from the small mirror E. If that adjustment had been such that the distance E F were exactly the focal distance of that mirror, the rays would be reflected *parallel*, as before shown; but, as it is rather more than the focal distance, the rays slightly converge after the second reflexion, and then either fall upon a single lens, or pass through two lenses, H K, as in the figure, to be converted by them into parallel rays before they enter the eye. It will be understood, from what has been before stated, that the observer does not view the image F, but the image I, which is so much nearer to the eye, that it appears under a large angle compared with that under which the image F would be viewed.

The magnifying power of this construction of the reflecting telescope, is thus determined:—multiply the ratio between the focal lengths of the two mirrors, by the ratio between the distance F I and I H:—thus, if B F be 10 and F E be 2, then will the ratio of the former to the latter be 5 to 1 or $\frac{5}{1}$; again, if the distance F I be 10 and I H be 1, then will that ratio be 10 to 1 or $\frac{10}{1}$, which multiplied, into the former, gives 50, as the magnifying power.

70. M. Cassegrain proposed a slight modification in the construction of the Gregorian Telescope, (so called from its inventor), which consisted in substituting a *convex* second reflector for a concave; and the focal distances of the two mirrors were adjusted to this new condition of the apparatus. The construction, however, in other respects, was similar to that of Gregory. The rays, coming from a distant object, are reflected by the large speculum in such a manner as to enable them to form an image in the focus; but, being intercepted by a convex speculum, they are reflected from its surface without having focalized, and then gradually converge to a focus in the eye-tube, where they are in a condition to be viewed by the eye-lens.

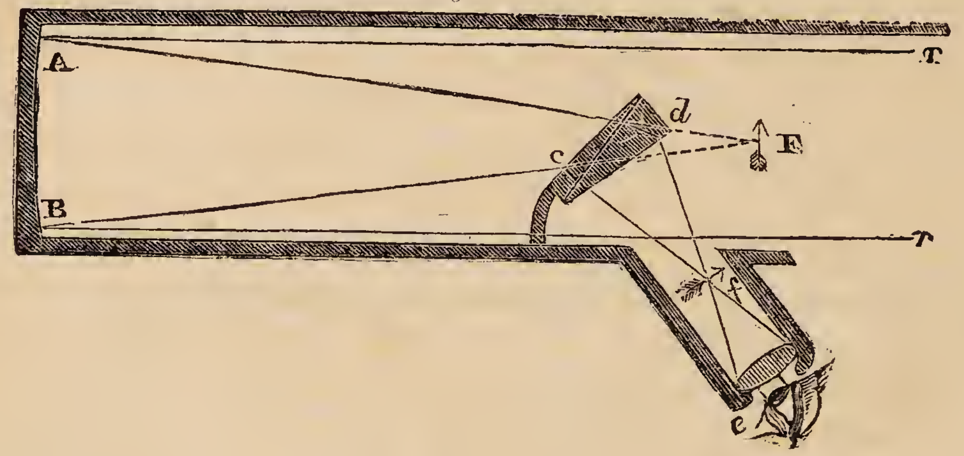
The circumstance that the rays of light do not cross each other in passing from one speculum to the other of the Cassegrainian Telescope, gives a greater clearness of view than when the Gregorian form is used. Captain Kater found, that, when he employed telescopes of these two constructions, in which the focal powers of the specula were equal, and therefore the magnifying power equal, the Cassegrainian gave a clearer and more distinct image than the Gregorian; and that, by varying the aperture of the Cassegrainian until the distinctness was equal in the two instruments, the surface of the exposed speculum in the Cassegrainian was only 4·63, at the time that the Gregorian presented a surface of 10·871: thus making it appear that a smaller diameter of tube will, on the Cassegrainian construction, produce as clear an image as a larger diameter on the Gregorian construction. It was on the Cassegrainian construction that Mr. Short, an eminent optician of the last century, made a great number of telescopes, which have gained much celebrity.

71. The Newtonian telescopes have been proposed by Sir D. Brewster to be improved by a new arrangement of the second reflecting body; or rather, by supplying the place of a second reflector with a *refracting* body. The reasons for this suggestion were, 1st, That a large quantity of light is always lost by

reflexion, however brilliantly the surface may be polished; 2nd, The liability which must exist of colour being produced, by any irregularities in the curvature or polish of the reflector.

To obviate these defects, as far as the second focalizing body is concerned, Sir D. Brewster suggested the following modification of Newton's arrangement. A B, (fig. 11,) is the great speculum, and F is the point at which the rays, *r* A and *r* B

Fig. 11.



would be brought to a focus after reflexion. So far it resembles the Newtonian. The rays, however, meet at *c d*, an apparatus which modifies their path, but without reflecting them as is done in the former instance: *c d*, is an *achromatic* prism; by which term is meant two prisms, one of crown-glass, and the other of flint, placed together, so that the colour produced in passing through one of them, by the decomposition of white light, is neutralized by the action of the second, which collects all the colorific rays into one compound ray of white light. But, although the *colour* is corrected by this co-operation, the refractive power is not extinguished, but exists in sufficient force to draw the rays obliquely downward towards *f*, where they are focalized, and an image formed, which is viewed as before by a convex lens, *e*. It has been estimated that the loss of light, which must inevitably accompany every instance, either of refraction or reflexion, is only one-fifth as much in this arrangement, as with the reflecting surface used by Newton.

72. In speaking of different telescopes, we have stated, that the magnifying power is estimated by applying certain formulæ, when the focal distances of the lenses have been obtained. But to determine the latter is a point of much difficulty; and to obviate, in some degree, the necessity for its determination, the following mode of measuring the power of a telescope has been adopted. At about 100 or 200 yards distance from the telescope, place a plate of brass, or a piece of card-board, with a

round hole cut in its centre, about an inch in diameter. Place there likewise another piece of card or plate-brass, and cut in it a *square* hole, each side of which shall be exactly equal to the diameter of the circular hole in the other card or plate. Adjust the focal distance of the instrument by lengthening or shortening its tube, until the circular opening is brought exactly into the focus. Then view the circular opening through the telescope with one eye, at the same time that you view the rectangular opening, without the telescope, by the other eye. Under these circumstances, the circular opening, being magnified by the telescope, appears much larger than the square opening, which is seen without such aid: the latter is therefore to be brought nearer to the eye, until the *real* magnitude of the aperture, seen by the one eye, is exactly *equal* to the magnified aperture seen by the other eye. We have now the means of measuring the magnifying power of the telescope; for we have only to divide the distance of the *circular* opening from the eye, (in feet or yards,) by the distance of the *square* opening from the eye, and the quotient will give the magnifying power. All such contrivances are called *Dynameters**, or *measurers of power*. Many arrangements of a very elaborate description have been at different times proposed for this purpose.

73. Such, then, are the principal modes of constructing this valuable instrument, which has furnished astronomers with the means of extending their researches to an extent, never dreamed of by those who know not the power of the telescope. A train of the most splendid discoveries and computations has followed its introduction; in which the master-minds of civilized Europe have been engaged with an ardour and an intensity of feeling, which those, who are unacquainted with the beauties of mathematical science, can scarcely conceive.

74. Shortly after Galileo had given the first impulse to this new order of things, Huygens, an illustrious name in the history of science, discovered a faint ring of light round the bright orb of Saturn. He watched it attentively for a long period, and at last perceived that it was no longer a *line* of light, but an *elongated ellipse*, which gradually gained in breadth. This ellipse decreased after a time, and returned again to its former appearance as a *line*. At last, he acutely concluded, that it was a *ring* round Saturn, which he had been viewing *edgeways*, and which he had consequently seen as a *line;* or

* A compound from the Greek, δυναμις, *power*, and μετρεω, *to measure*.

obliquely, when the ring appeared as an ellipse. This ring can be very distinctly seen by the aid of the telescope.

75. Soon after that period, Cassini, another distinguished astronomer, discovered that the planets Jupiter, Mars, and Venus, have each a constant rotation round its axis, like the earth: that is, a *daily* rotation, if we bear in mind that what constitutes a day, is the period during which a planet revolves *once* round its axis: and, although the times which two planets take for that rotation may be different, yet, the term *day* may be applied to each one. Cassini also discovered three moons moving round Saturn, in addition to the ring which Huygens had discovered. He likewise determined that Jupiter was not a perfect sphere, but was *spheroidal*, having something like the shape of an orange; and he calculated the times that his little attendant-moons occupied in going round him.

76. The telescope, from its power of making small stars visible which would otherwise be quite beyond the range of human eye, afforded the means of making large and important additions to the catalogues of the stars; and this was a service which Flamsteed, the Astronomer Royal in England, at the time of Newton, rendered to science. He produced a catalogue of the stars, which, for value, completely eclipsed all that had been done before his time.

77. The great Newton was not a *practical* astronomer, so far as regards making observations on the heavenly bodies; but to Physical Astronomy, or that branch of it which investigates the laws, by which the different parts of the solar system retain their wonted distances from each other, and act on, and are acted upon by, each other, Newton rendered perhaps the most splendid assistance, that the genius of any one man has ever given to physical science: we mean, by the discovery of the law of *gravitation*, by which the distances of the planets from the sun,—the periods of their revolutions,—the densities of their masses,—their action on the fluid portions of other planets, and a long train of important consequences, may be laid down with a precision and certainty, which afford the most convincing evidence of the truth of the principles, on which they are founded.

Newton also rendered essential service to the telescope, and through it, to the cause of Astronomy, by his discovery of the *compound* nature of *white light;* by which the means have been devised of correcting, almost entirely, the coloured fringes which, in the common construction of a telescope, are so great a detriment to distinct vision.

78. It was about the same period, too, that Halley, another cotemporary of Newton, first laid down any definite law respecting *comets*. Our readers will recollect that two or three years ago public attention was strongly directed to a comet, called *Halley's comet*. This was the first, whose return, after a long period, had been predicted. Halley discovered that a comet, visible in 1682, was moving in a very eccentric and elongated ellipse; and from a consideration of the distance between it and the sun at that period, and of the velocity with which it was moving, he calculated that it would return again to the same point of its elliptical orbit in a period of between seventy-five and seventy-six years. That prediction was fulfilled by its re-appearance in the year 1758; and was further confirmed by its appearance in November, 1835.

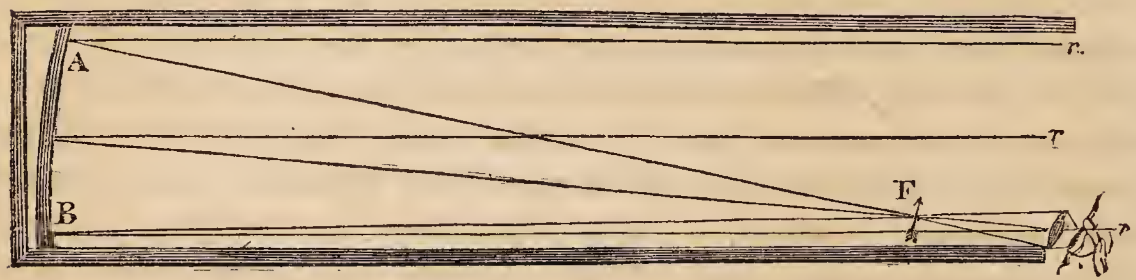
To merely epitomize what has been done from the time of Newton to our own days, would be to give an account of the labours of Mayer, Bradley, Maskelyne, Clairaut, Lagrange, Laplace, and a host of names destined to float imperishably down the stream of time. This is far beyond our purpose; but there is one name, which is too closely connected with the telescope, to admit of a slight or hasty notice: we mean the name of HERSCHEL.

79. The late Sir William Herschel constructed a telescope, whose magnifying power exceeded all which had been done previously, or since. The reader will have perceived that reflecting telescopes focalize the rays at three different parts of the tube, according to the adjustment of the mirrors and lenses. Gregory's telescope is used by the observer in a similar way with the refracting telescope; that is, the observer has it turned directly towards the object at which he looks. Newton's is so constructed, that the observer has to look into the side of the tube, having the object to the right of him; while Brewster's adaptation requires that the observer should have his back *nearly* turned towards the object. Herschel's arrangement was, however, different from all of these; inasmuch as the observer *actually* turns his back upon the object which he desires to see.

Let us suppose A B, fig. 12, to be a concave reflector, and r A, r B, to be nearly parallel rays proceeding from a distant object. The reflector, A B, is not placed symmetrically across the tube, but has such a degree of inclination given to it, as will bring the rays to a focus at F, near the margin of the mouth of the tube. The eye of the observer being now placed at that point, he will see the image formed by the focalization of the rays. The object to be attained in thus bringing the rays to a

focus at the margin of the tube instead of at the centre of its diameter is, that the body and head of the observer may intercept as few rays as possible; for it will be seen that it is quite impossible for him to look into the tube without obstructing the passage of some of the light proceeding from the object. It is

Fig. 12.



therefore a desideratum of no small importance, to limit that obstruction to as small a quantity as possible. This is effected by a certain obliquity given to the position of the reflector, by which the focus is thrown from the centre of the diameter of the tube to the margin.

80. As this telescope was, in many respects, the most remarkable which had ever been made, we will describe it somewhat more minutely, from Sir W. Herschel's own account of it, published in the *Philosophical Transactions*, for 1795.

He began it in 1785, by the pecuniary aid afforded to him by King George III.; and superintended the whole of the construction himself; employing none but common workmen, who received their orders from himself personally; and often having forty workmen engaged at the same time. In February, 1787, he had the first view through the telescope, although it was not finished till some time afterwards. It was, however, not till August, 1789, that the telescope was finally completed; for three specula had been made before a perfect one was obtained.

The tube was 39 feet 4 inches in length, 4 feet 10 inches in diameter, and made entirely of iron. Sir W. Herschel computed, that a wooden tube would have exceeded the weight of the iron tube, by at least 3000 lbs. The body of the tube was made of sheet-iron, joined at the edges of the sheets by a kind of seam, but without rivets. As the sheets of iron were each only 3 feet 10 inches, by 2 feet, a large number must have been thus joined together. The complete sheet of iron, 40 feet long by 15 broad, was then sunk into a concave hollow, which gave the first germ of a tubular form to it, which arching was completed by building up a sort of *centering*, like the centering for the arch of a bridge; and the sheet was gradually drawn into the circular form round these centerings.

The great reflector, A B, fig. 12, was $49\frac{1}{2}$ inches in extreme diameter, or 48 inches of polished surface. The thickness was equable in every part, and about $\frac{3}{4}$ of an inch, and weighed 2118 pounds. The speculum was fixed in an iron ring, to which was fitted a flat tin cover, to be used for preserving the speculum from damp, &c., when not in use. A speaking-tube was fitted to the side of the telescope, by which the observer could communicate the result of his observations to an assistant below, who was stationed in a small house, and provided with various instruments for measuring time, the positions of the stars, &c. The stupendous tube was elevated by a complicated assemblage of machinery; by which, with the assistance of pulleys, the telescope could be directed to any object, either near the zenith, or near the horizon. In order to obtain a horizontal motion, the whole machinery, scaffolding and all, was made to move round a central axis on rollers, which rollers worked upon the top of two strong, concentric, brick foundations, the diameter of the outer circle being 42 feet and that of the inner 21 feet. The eye-pieces, through which the observer viewed the reflected image of an object, were held at the mouth of the tube, by a sliding apparatus, by which the attention could be directed to any particular part of the speculum.

After this stupendous instrument had remained in its place about 30 years, the framework was found to be greatly decayed: and the whole was taken down, and replaced by a smaller telescope on the same construction by Sir J. F. W. Herschel, the distinguished inheritor of a distinguished name.

81. No sooner had the great telescope been erected by Sir W. Herschel, than he began an important series of discoveries by its means. He discovered the sixth satellite of Saturn, (five only having been previously known,) on the day that this instrument was completed. Six years before this period Herschel had distinguished himself by a discovery of a nature quite distinct from anything which had occured for many centuries; that of a *new planet* belonging to the solar system. We have seen that a large accession to the number of heavenly bodies had appeared, and had been made objects of observation and calculation: fixed stars, comets, and satellites or moons, had been from time to time added to the list of known bodies; but no *new planet* had been discovered from the days of the most ancient nations of the world, to the time of Sir W. Herschel. The planet thus discovered had seemed of so small a size to the naked eye, and so indistinct as compared with most of the other planets, having likewise so slow a motion that it had been set down in

the catalogues of the *fixed* stars; that it had thus probably escaped the observation of previous astronomers.

This planet was named by the discoverer, the *Georgium Sidus*, or *Star of George*, in compliment to his royal patron; but it has since been more generally known by the name of *Uranus*, at least among foreign astronomers; and sometimes by the name of its discoverer, HERSCHEL. Great as is the distance of the earth from the sun, it bears but a small proportion to that of Herschel from the same luminary. The earth is about 95,000,000 of miles distant; but Herschel is more than nineteen times as distant from the sun. It is larger than Mercury, Venus, Mars, or the earth; but it is smaller than Jupiter, or Saturn. Its enormous distance from the sun renders its annual revolution round that luminary a very lengthened period; inasmuch as it occupies more than 30,000 of our days to pass from summer to summer, or from spring to spring! If we conceive a winter lasting for forty-two of our years, we may form some idea of the coldness of Herschel, as compared with that of the earth: indeed, it has been computed that, even in summer, the heat of the sun must be so feeble, at the great distance which Herschel is placed from it, that water could not exist except in the solid form of ice.

82. But not only did Sir W. Herschel discover this very remote planet. He distinguished, one by one, by the aid of his large telescope, six luminaries revolving about it in the manner that Jupiter's moons revolve about the body of that planet. The same able astronomer also, with the same magnificent instrument, discovered that the ring which surrounds the planet Saturn, is not only divided into two concentric belts by a dark circle, as was discovered by Cassini, but that the ring revolved about the planet.

83. From the time of Sir W. Herschel, to our own days, the discovery of new bodies in the heavens has been chiefly limited to four little planets, which were discovered very early in the present century. 1. The planet Ceres, discovered by Piazzi: 2. and 3. The planets Pallas and Vesta, by Olbers: and 4. Juno, by Harding. Since this period, the preparation of extensive catalogues of Nebulæ*, and double stars, by Sir J. Herschel, and Sir J. South, forms, perhaps, the most important additions to the list of the materials, to which the power of mathematics will be directed by the physical astronomer.

* Clusters of fixed stars so small, or so distant, that they present a dim *cloudy* appearance to the naked eye; whence they have been termed "*little clouds.*"

84. It is desirable, now, to take notice of an *effect* of the compound nature of white light, which has been productive of much dissension, and has given birth to the exercise of much ingenuity for its correction: we allude to the chromatic fringes seen round an object, when viewed through a telescope. If we look at an object through an opera-glass or a common telescope, we generally find that the edges, or outlines, are bordered with colours, which greatly interfere with distinct vision.

Now, the cause of these fringes is to be found in the different refractive powers possessed by the different coloured rays of light. The violet are more bent or refracted from their original path than the red rays. If, therefore, the focal distance of a lens be calculated for the red rays, it will not precisely coincide with the focus of the violet rays, because the latter, being more bent, will approach the second surface of a lens more obliquely, and will therefore have a longer path of convergence to travel, before they focalize, than the red rays; and hence will approximate to a point at a greater distance behind the lens than will the red rays. Under the most favourable circumstances, the focal distance of the red rays is about $\frac{1}{40}$th part shorter than the focal distance of the violet rays; hence, if the focus of an instrument be adjusted for the red rays, a ring of violet light will surround the image.

85. In order to correct this defect, John Dollond, about the year 1754, constructed a compound refracting apparatus. It consisted of a hollow trough, made of two plates of glass, placed at an angle with each other; and in the trough, or hollow, he placed, in an inverted position, a common glass prism, and filled up the vacant space with clear water. He then contrived to vary the angular opening between the two plates of the trough, until the refraction produced by the water exactly counterbalanced the opposite refraction of the glass. But he found that a ray of light, coming through this compound prism, was still bordered with coloured fringes; so that the desired correction was not attained. It was therefore necessary to extend the inquiry; and this he did by varying the angle of the water-prism, while that of the glass-prism remained constant; and he found that, when the refracting power of the water was to that of the glass as 5 to 4, the coloured fringes were destroyed.

We endeavoured, in previous details, to show that the refraction through *lenses* might be compared to, and deduced from, refraction through *prisms*. Dollond, acting upon such known connexion, now made his prism of water into a deep convex lens of the same liquid, and his prism of glass into a concave

glass lens; and found the correction of colour to be as successful as before. As the dispersive and refractive powers of different solid transparent bodies differ as much as those of glass and water, Dollond next directed his attention to the preparation of two solid lenses, which should correct each other's colour, without destroying the refractive power. He prepared two prisms of crown and flint-glass, of such angles as to refract equally; which occurred, when their refracting angles were respectively 29° and 25°. By this adjustment, all refraction or change of direction was destroyed; but the coloured fringes were perspicuous. He then so adjusted the angles, that, instead of making the refractive powers equal, he equalized the dispersive powers; which he found to occur when the refracting angles were about as 7 to 4. By applying this mode of adjustment, therefore, to two lenses, instead of prisms, he attained a refractive power without the production of coloured fringes.

86. The son of Mr. John Dollond made another improvement in these compound lenses, by an adjustment which nearly destroyed the *spherical* aberration, as well as the chromatic. We have before stated, that, if a lens be a portion of a perfect sphere, the exterior rays, or those which impinge nearest to the circumference, are not contracted to a focus at exactly the same point at which the rest of the rays focalize. This error can be corrected by a peculiar curvature of the lens; but the difficulty of practically attaining that curvature, has led to its abandonment. Mr. Peter Dollond contrived a *triple* lens, consisting of a double-concave lens of flint-glass, enclosed between two double-convex lenses of crown-glass. The particular curvatures which he gave to the six surfaces of these lenses are not exactly known; but they were such as to correct not only the chromatic error arising from the unequal refrangibility of the differently coloured rays, but also a considerable portion of the spherical error arising from the form of the surface of the lens.

These adaptations made the extreme rays, the red and violet, neutralize each other, when passing through these compound lenses; but still the intermediate rays were not quite neutralized; and further researches were made to improve the combination of lenses. In 1787, Dr. Blair, Professor of Astronomy at Edinburgh, pursued a series of experiments on the refractive and dispersive powers of different liquids. He used a small brass prism, through which a hole was perforated, and into which he introduced a drop of any liquid, the optical properties of which he wished to examine. He then placed behind the hole in the brass prism, a number of glass prisms in succession, the refract-

ing angles of which greatly differed. These latter were inverted with respect to the brass prism; and the object was to determine such a fluid for filling the aperture in the brass prism, and such an angle of the glass prism, as should completely extinguish coloured fringes in any object seen through both prisms, but without destroying the refractive power. He found that muriatic acid, when combined either with antimony or mercury, had a great dispersive power. He then joined a double-concave lens of crown-glass, with a plano-convex lens of essential oil, of high dispersive power, and a plano-concave lens of essential oil of a lower dispersive power. With this complex arrangement, the coloured fringes were almost entirely extinguished; and he afterwards attained the same object by a more simple combination, which consisted of muriate of antimony, enclosed between two watch-like glasses, placed with their convex surfaces in contact, by which the enclosed fluid was rendered double-concave. On the face of one of the glasses he then fixed a plano-convex lens of crown-glass, and on the other a meniscus* of the same material. This combination almost completely annihilated colour in the refracted light.

87. Since the above-mentioned period, a great deal of attention has been devoted to the subject of *achromatic* or *colourless* glass, with the hope that such a combination might be devised as would preclude the necessity of employing fluids as one of the refracting substances. In this inquiry, Sir D. Brewster, Sir J. Herschel, Professors Barlow and Faraday, have particularly distinguished themselves. Mr. Barlow has given the following curvatures for two lenses, the combined operation of which, is such as to give achromatic images. Suppose the focal length of the telescope to be 80 inches; then one lens is formed of plate-glass, is double-convex, and has the radius of curvature of one surface 271·9 inches, and of the other surface 27·19 inches. The other lens is of flint-glass, is double-concave, and has the radius of curvature of one surface 27·61 inches, and of the other 28·4 inches.

88. We must now give a brief account of the modes of manufacturing the two parts of telescopes, on which the value of the instrument mainly depends; viz., the *lenses* for refracting telescopes, and the *specula* for reflectors.

We will first treat of *lenses*. The diameter of the tube of the telescope, the focal length of the lenses, and the degree of curvature to be given to them, having been previously arranged; a

* A *meniscus* is a lens convex on one side, and concave on the other; the concavity having the greater radius.

piece of sheet copper is taken, and a well-defined arc drawn upon it, which has a radius equal to half the focal distance of the lens, (if plano-convex) and is a little longer than the diameter of the aperture of the telescope. The part of the copper exterior to this curve is then cut away, leaving a *convex* edge which is to act as a gauge. A similar arc is then cut in another piece of copper; but the *concave* side of the arc is in this case required. Two circular brass plates, about $\frac{1}{10}$th of an inch thick, are then prepared,—the diameter of which exceeds the intended breadth of the lens by half an inch; and these are soldered upon a small leaden cylinder of the same diameter. These two surfaces of brass are then turned, by means of a lathe, into curved surfaces, the one convex and the other concave,—the curvatures corresponding with those of the copper gauges before made. Should the convexity of the one not coincide exactly with the concavity of the other, they are ground upon each other, with emery interposed.

The glass for the lens (for the *grinding* of which these tools are prepared) should be of a straw colour, and having both surfaces parallel. It is cut into a rough circular shape, by scissors or pincers. The rough edges are then removed by a grindstone, and the glass is fixed by black pitch to a small wooden handle or cylinder. It is then ground upon the brass gauge with emery; the convex or concave gauge being used, according to the desired form of the lens, and the gauge being firmly fixed to a bench, the motion of the hand of the workman is circular, so as to produce the desired curvature of the lens. When the surface of the glass exactly coincides with that of the tool, the proper shape is acquired, and the asperities on the surface are removed by employing, successively, different portions of emery, of increasing fineness. At intervals, during the operation, the two tools are ground upon each other, so as to preserve a constant curvature. When the surface of the glass is properly curved, it is removed from the wooden handle, and its surfaces reversed, in order that the second surface may now be operated upon in the same way as the first.

The lens is now ready for *polishing*, which is an operation requiring particular care and judgment. If the lens be *convex*, the concave tool is covered to the fifteenth of an inch in thickness, with a layer of pitch, hardened by a little rosin. The equability of this layer of pitch is ascertained by pressing the convex tool upon it—a piece of thin paper being interposed between the two; if the marks of the paper be seen on every part of the surface of the pitch, the layer is equable, and ready

for use. The lens is then worked on this bed of pitch, with oxide of tin, or red oxide of iron, until a perfect polish is obtained. As the friction gradually warms the pitch, the polishing becomes more easy of execution.

Another mode of performing the process of polishing, is to cover the bed or stratum of pitch with a piece of cloth, which can be pressed close to it by the application of the concave tool. This method is easier, but not so perfect in its results.

In these processes, it will be seen that the hand of the operator gives the proper motion to the lens in the act of grinding or of polishing. For concave lenses, however, a machine is sometimes employed, which consists of a leaden wheel, with the same radius as the curvature of the lens, and with a circumference which has the same convexity as the lens is concave. This wheel is fixed upon a turning-lathe, and the lens, which is held in the hand, is ground upon the circumference of the wheel with emery. It has, however, been doubted whether such great accuracy can be attained by this method, as when manual labour alone is employed.

The process of polishing a lens is followed by one which is called *centering*; that is, finding the centre of the spherical surface;—or rather, giving to the two surfaces of the lens, if it be double and equally convex, such a figure that the axes of the two spheres, of which the surfaces are segments, shall be in the same right line. The lens is attached, by means of pitch and of a chuck, to the mandril of a lathe, and before the pitch becomes cold, the position of the lens is changed by the hand till, by revolving the mandril, (as in the act of turning,) any object seen through the edges of the lens, or any object seen by reflexion on its outer surface, remains steady to the eye during the revolutions. When the adjustment is attained, the lens is cut into a circular form by being ground on its edge with emery. When the shape is finally attained, the pitch, emery, &c., is washed off with spirits of wine.

Spectacle-glasses, not requiring such rigid accuracy as the lenses of telescopes, are ground, a hundred or more at a time, by machinery.

89. We must now direct attention to the formation of the *specula*, or mirrors used in the reflecting telescopes. The ingredients of which these specula are made, are copper, grain-tin, and arsenic, in the proportions of 32 copper, 15 grain-tin, and 2 arsenic. By the addition of a small portion of a more costly material, silver, Mr. Edwards, in 1787, prepared speculum-metal, which has never been exceeded for brilliancy or hardness.

The specula are cast in a fine loamy sand, slightly wetted, and well beaten. The bed of sand is prepared, and a mould made for the metal by means of the pattern, which is made of brass or pewter; air-holes being left at intervals. The 32 parts of copper are then melted in a crucible, and when reduced to a fluid state, the tin is mixed with it, the latter having been previously melted in a separate crucible. The mixture is then stirred with a large wooden spatula, and poured into a quantity of cold water, by which the melted liquid is separated into a great number of small particles. One portion of silver, and one of brass (which is sometimes added), are then melted in a separate crucible. The mass of silver and brass, and the small fragments of copper and tin, are now put altogether into a crucible, and when completely melted, the proportional quantity of arsenic is added. When the whole is fused, and the *scoria*, or *dross*, removed, the liquid metal is poured into the flask, or mould, where it remains till solid. It is then taken out, and placed among hot ashes or coals, for the purpose of annealing the metal, where it is allowed to cool gradually. When cold, the metal, which now is roughly formed into the proper spherical shape, is ground on a common grindstone, to remove the roughnesses.

The process of *grinding* and *polishing* to the true figure now commences. The gauges and tools are made much in the same way as those for lenses. The convex tool, if the speculum be concave, is worked upon the surface of the metal, with emery of different degrees of fineness. The tool has a circular motion given to it by the operator, as in the former processes; and the operation is continued until the surface is perfectly spherical, and free from the slightest asperities. The speculum is then rubbed with a tool, on which is fastened a common blue hone, in order to remove the slight scratches which the emery tends to make on the surface.

The speculum, being now ready for *polishing*, an elliptical leaden tool is covered with black pitch, about $\frac{1}{20}$th of an inch in thickness, and formed into a perfectly smooth surface, by the application of a brass tool to it. Red oxide of iron is then applied, in a finely powdered state, to the surface of the pitch-polisher, and the latter is worked upon the speculum in the way before described, until the surface is perfectly brilliant. The application of an elliptical polisher, in this way, is found to give a parabolic figure to the speculum, which is a form most desired in practice.

Lord Oxmantown has invented a machine for grinding and

polishing large specula by machinery; and Dr. Green, of Cork, has devised another machine, for operating on specula of medium size; but we believe the general practice is *by hand*, such as we have described.

90. We will now briefly describe the mode of making brass tubes, such as those used for telescopes. These tubes are made of sheet-metal, which is cut, by means of shears, into the proper form. When the diameter of the tube has been fixed upon, a mandril is prepared of the same diameter, and a slip of metal is passed round it to ascertain the proper width of the sheet-brass. The piece having been carefully cut from the sheet, is then brightened by filing the surface about a quarter of an inch deep at the opposite edges on the same side. It is then bent round a wooden cylinder by means of a mallet, until the edges of the slip of metal meet; by which the brightened edges come next each other, and a proper surface is presented for the reception of the solder. The tube is then bound round with hoops of wire, in order to retain it in its proper form during the operation of soldering. The tube is then ready for soldering, by the introduction of borax and spelter-solder. The borax is pounded with water to the consistence of cream, and is rubbed along the joining on the outside, and poured into the joining in the inside, of the tube. This is done by means of a small iron rod, which also serves to take up portions of spelter-solder, to be laid upon the joining with the borax. The fire, which is applied to heat the tube during this process, is made of small black coke; as blazing coal injures the metal. When the solder and borax are applied to the *suture* or *joining* of the tube, this is held over the fire until it becomes red-hot, at which time the ingredients become melted, and flow into the seam. The brass attains such a degree of temperature that, if care be not observed, it will be either burnt or melted at some parts.

The wires are then removed, and the tube is placed in dilute sulphuric acid, after which it is well washed. The tube then undergoes the process of *drawing*. It is pushed upon a mandril of a proper size, while a perforated steel plate encompasses the tube; and, by an adaptation of powerful machinery, the mandrils and the tube are drawn forcibly through the aperture in the steel plate, by which the tube is made of perfectly equal thickness throughout, hard, and smooth. The tube is now made, and is fit to undergo all those processes of adjustment, which fit it for the employment of the optician.

91. The exterior fittings of a telescope are, of course, not of much importance to the understanding of the principle on

which telescopes act; and they are so varied that it would be impossible for us to enter into much detail on the subject. We may, however, remark, that perfect fixation is a most desirable object when the heavenly bodies are to be viewed, because the slightest tremor disturbs the image of the object formed within the telescope. Professor Robison observed, that a person walking in a room in which astronomical observations are being made, prevents the Astronomer from seeing the object distinctly, by the slight shaking imparted to the instrument; nay, that the very *pulsation* in the body of the observer, agitates the floor enough to produce this effect, when the telescope has a great magnifying power. He compares the effect to the tremor observed in the wire of a piano-forte, when vibrating. The same talented philosopher remarks, that fixing one end of the telescope against something which is not very elastic, has a great effect in deadening and stifling the tremors of the instrument. On one occasion he took a fine telescope, made by Short, a distinguished optician of the last century, and laid the tube on a great lump of soft clay, and pressed it firmly down upon the clay. Several persons, ignorant of the object in view, looked through the telescope, and read a table of logarithms at the distance of 300 yards. He then put the telescope on its usual stand, and pointed it to the same object; none of the company could now read it at a greater distance than 235 yards, although they could perceive no tremor: yet there must have been a minute tremor, which occasioned the difference of distance at which the book could be read.

92. Sir W. Herschel proposed a mode of estimating the power or value of a telescope, which had not occurred to previous observers: that is "Space-penetrating power." It was thus illustrated:—On one occasion he directed a 20-foot Newtonian telescope towards the steeple of a church, in the dusk of the evening; and could see the time indicated by the church-clock; whereas, without the glass he could not see even the steeple itself. Now, Herschel knew that the reason why he could not see the hour-lines of the clock with the naked eye was, that it was too far distant; but that he could not see the outline of the steeple was not due to the great distance, but to the darkness of the evening. He therefore considered the power of the telescope in a *two-fold* point of view. 1st. Its *space-penetrating* power, by which he was enabled to see an object, when the light of the sky was too feeble to permit him to see it with the naked eye; and 2nd. The *magnifying* power, by which a small distant object became magnified to such a size as enabled him to see it.

This gives an additional value to what are called *night-glasses*; which are short telescopes, used by mariners, when the darkness of evening prevents objects from being clearly seen without their aid. Night-glasses generally have the power of penetrating six or seven times farther into space, than can be accomplished by the naked eye: this is to be considered independent of the magnifying power, although connected with it.

On one occasion Sir W. Herschel saw the ring of Saturn, and one of his satellites, with the large telescope, without an eye-lens, when the magnifying power was only 60 or 70; but the penetrating power made up for the diminution of the magnifying power.

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93. Here we conclude our account of the telescope: an instrument which has effected so many wonderful discoveries; and doubtless many more discoveries wait but for the improvement of our modes of observation and research. "The day may yet be coming," as an eloquent divine remarks, "when our instruments of observation shall be inconceivably more powerful. They may ascertain still more decisive points of resemblance. They may resolve the same question by the evidence of sense, which is now so abundantly convincing by the evidence of analogy. They may lay open to us the unquestionable vestiges of art, and industry, and intelligence. We may see summer throwing its green mantle over these mighty tracts, and we may see them left naked and colourless after the flush of vegetation has disappeared. In the progress of years or of centuries, we may trace the hand of cultivation spreading a new aspect over some portion of a planetary surface. Perhaps some large city, the metropolis of a mighty empire, may expand into a visible spot by the powers of some future telescope. Perhaps the glass of some observer, in a distant age, may enable him to construct the map of another world, and to lay down the surface of it in all its minute and topical varieties. But there is no end of conjecture, and to the men of other times we leave the full assurance of what we can assert with the highest probability, that yon planetary orbs are so many worlds, that they teem with life, and that the mighty Being who presides in high authority over this scene of grandeur and astonishment, has there planted the worshippers of His glory."

XI.

A SOAP-BUBBLE.

Here, awful Newton, the dissolving clouds
Form, fronting on the sun, thy showery prism;
And to the sage-instructed eye unfold
The various twine of light, by thee disclos'd
From the white mingling maze. Not so the boy:
He wondering views the bright enchantment bend,
Delightful, o'er the radiant fields, and runs
To catch the falling glory; but amaz'd
Beholds th' amusive arch before him fly,
Then vanish quite away.—Thomson.

1. If the educated man were to compare his present perceptions and feelings with those which regulated his mind in boyhood, he would probably find that time had, indeed, softened the impressions then conveyed; but that, though it had extended the sphere of their action, it had not changed their character. In early life, when the works of nature or of art, present themselves in all the freshness of novelty, the sensations, which perception supplies, are exquisite and pure. To such a mind the world is young, fresh, and beautiful; and, unless that mind have become perverted and depraved, those very qualities which so much delighted childhood continue to delight manhood; and even in old age, satiety is unknown. To him who has been so fortunate as to select Nature for his study and his guide, the amusements of youth form part of the study of after-years. The glowing colours of the rainbow, and of the soap-bubble, in the one case, gratify the eye which gazes upon Nature in one of her loveliest garbs, and prepare the mind for the perception of the beautiful:—in the other case, she is not only present, but speaks an eloquent language which it is the object of her student's life to understand and to interpret to others. One of our greatest philosophers, in reference to his own life, says—"I have been like a child gathering pebbles on the sea-shore;"—and this expression points out to us with what feelings of eager curiosity, simplicity, and delight, he pursued his studies. The simple and unprejudiced mind of the child joined to the vigorous under-

standing of the man, ought, indeed, to constitute the faculty with which we should contemplate "the great ocean of truth," which the same philosopher declares "lay undiscovered before him."

2. If the great Newton, then, did not disdain to make a soap-bubble an object of his study, we need not hesitate to invite our readers to an investigation of its appearances and properties. We propose, therefore, to inquire into, *first*, The formation of a soap-bubble in the manner which will be best adapted to the present inquiry: *secondly*, The optical phenomena presented by a soap-bubble, as well as by other substances from which the same results are obtained, when we shall present the student with an entirely new set of experiments on the colours of thin plates and a novel mode of producing them: *thirdly*, The theories by which such phenomena are explained: and *fourthly*, An illustration of the repulsive property of heat by means of Newton's rings; together with a set of new experiments illustrative of calorific repulsion.

3. i. Most liquids, when agitated, exhibit on their surface a frothy appearance, in consequence of the air escaping in small bubbles, which air being surrounded by a portion of the liquid, a film remains as a sort of case to the air within; and, provided the liquid be viscid, or tenacious, the film will remain for a considerable time in its inflated state. Such liquids as the essential oils, alcohol, turpentine, &c., can be blown into bubbles; and by adding a small portion of soap to distilled water, this is made sufficiently tenacious to be blown into a bubble also. The usual method is to form a bubble within the bowl of a tobacco-pipe, and so inflate it by blowing through the stem. It is also produced by introducing a capillary tube (which is a tube of very small bore) under the surface of soapy water, and so raising a bubble, which may be inflated to any convenient size. It is then guarded with a glass cover, to prevent its bursting by currents of air, evaporation, and other causes.

4. When a bubble is blown from a tobacco-pipe, and the upper part of the bubble is attached to the bowl, its form is generally elliptical. This arises from the effect of gravity; which, being resisted by the adhesion of the bubble to the pipe, draws the former into the elliptical form. When, however, the bubble is detached from the pipe, and allowed to float in air, it instantly becomes globular; since the air within presses equally in all directions. There is also a strong cohesive attraction among the particles of soap and water after having been forcibly distended; and, as a globe possesses less surface than any other figure of equal capacity, it is of all forms the best adapted to the

closest approximation of the particles of soap and water: this is another reason why the bubble is globular.

5. The bubbles formed in this way endure but for a brief space of time. The film of which they consist is of extraordinary thinness; and as evaporation is constantly going on from its surface, as the air within is subject to all the varieties of contraction and expansion from change of temperature, and as the soap-lather has a tendency to gravitate towards the lower part of the bubble, and consequently to render the upper part still thinner, it follows that one or other of these causes always interferes with the duration of the bubble beyond a few seconds.

6. By mixing a weak solution of isinglass with the lather, the bubbles may be blown larger, and their duration rendered longer. Another method of exhibiting the soap-bubble is to dip the mouth of a wine-glass into a weak solution of soap, and then to hold it in a horizontal position with its foot flat against an upright body, such as the window-shutter, in order to keep it steady. The film covering the glass, being in a vertical position, the gravity of the fluid tends to make it thicken at the lower part; and it becomes every where gradually thinner and thinner, till at length it bursts at the upper part from its extreme tenuity.

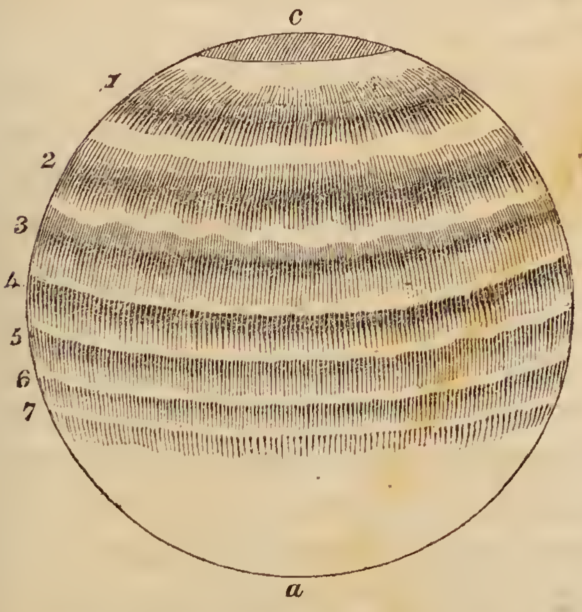
7. All these methods may, however, be superseded by the following plan (proposed by Dr. Reade), which has every thing to recommend it:—cheapness, practicability, and considerable duration. Indeed the latter quality has been hitherto so much wanted, that opticians have been compelled to refer their observations to other thin surfaces which have not the *ghostly* peculiarity of the soap-bubble, *i. e.*, of vanishing suddenly in the midst of an important observation.

8. The permanency of the soap-bubble, then, may be thus ensured. Into a six-ounce phial pour two ounces of distilled water. Place the phial and its contents in a vessel of water boiling on the fire. The water in the phial will soon boil, and steam will issue from its mouth, expelling the whole of the atmospheric air from within. When this occurs, throw into the phial a piece of soap about the size of a small pea, and then cork the phial,—at the same instant removing the vessel and the contained phial from the fire, otherwise the steam within the phial will burst it. Then press the cork farther into the neck of the phial, and cover the whole of the exposed cork with a thick surface of sealing-wax. If all this be done quickly, a very perfect vacuum will be formed within the bottle, when its contents are cold:—much better, indeed, than can be produced by the best constructed air-pump. The object of the sealing-wax is to prevent the return of the air into the bottle.

9. ii. When the bottle and its contents are cold, a bubble may be formed in the following manner. Hold the bottle horizontally in both hands, and give it a sudden upward motion, by which means the liquid will be thrown into a wave, whose crest touching the upper interior surface of the phial, the tenacity of the liquid will cause a film to be retained all round the phial:—probably two or three films will be so produced; but one is quite sufficient, and more than one are no inconvenience. A film being thus made, place the phial on its bottom, and the film will now form a section of the cylinder, being nearly, but never quite, horizontal; since one part is always somewhat higher than the rest, in consequence of the irregular jerk which forms it. The writer has found that the film in almost every case inclines from about 8° to 16° from a horizontal section. If the film be now observed, it will appear colourless, since it reflects almost all the light which falls upon it. By remaining at rest for a minute or two, its surface will exhibit considerable agitation. This is in consequence of minute currents of lather descending by their gravitating force down the inclined plane formed by the film:—this superfluous water trickles down the interior of the bottle into the liquid below. The upper part of the film first becomes drained to the necessary thinness, and this is the part which must be first observed.

From a point beyond the highest point *c*, fig. 1, as a centre, several concentric segments of coloured rings are produced: the colours (beginning from *c*) being as follows:—

Fig. 1.



1st order:—black, white, yellow, orange, red.

2nd order:—purple, blue, white, yellow, red.

3rd order:—purple, blue, green, yellowish green, white, red.

4th order:—purple, blue, green, white, red.

5th order:—greenish blue, very pale red.

6th order:—greenish blue, pink.

7th order:—greenish blue, pink.

On continuing to observe the film, the segments are seen to advance towards *a*, getting broader as they advance; while the film, by continual draining, becomes thinner and thinner. Now

as the various orders of colours depend entirely (as we shall hereafter prove) upon the various thicknesses of the film at different parts, it follows that, as the film gets thinner from *c* to *a*, the 7th order advances towards *a*, and is visible so long as the film is thick enough to produce this order; but when it becomes too thin, the 7th order disappears. During this time the other orders are, for the same reason, advancing towards the point *a*; and the 6th gradually disappears at *a*, when the film has become too thin to reflect this order of colours. In like manner the 5th, 4th, 3rd, and 2nd orders of colours expand and disappear, until the 1st order alone remains, occupying the whole of the surface of the film. Of this order, the red disappears first, then the orange, and lastly the yellow. The film is now divided by a well defined line into two nearly equal portions, one of which is black and the other white. This state of things remains for some time, till at length the film becomes too thin to hold together, and then vanishes.

10. In order to observe the phenomena here described, (and the observation generally lasts from twenty minutes to half an hour,) it is necessary that the bottle should be placed close to the window, so as to receive an uninterrupted light from the sky. It should also remain undisturbed during the whole observation; and all the colours should be viewed as nearly as possible at the same angle of reflexion, since it will be found, especially towards the close of the observation, that a considerable variation in the obliquity of the reflected angle produces an almost entire change of colour on the surface of the film.

11. The colours on the surface of the film are not faint and imperfect; nor are they supplied partly by theory and partly by observation (as is too often the case in science); but, on the contrary, they are most perfect and well defined, glowing with the most gorgeous hues, or melting into tints so exquisite, that we may look in vain for their rivals through the whole circle of the arts. They are, in fact, colours painted by the very hand of Nature, with materials the purest and most perfect, on which the eye lingers with fond admiration and delight. Indeed this cheap and simple experiment is well calculated to afford pleasure, both to those who are acquainted with the scientific principle by which the production of the colours is explained, and also to those who approach the subject for the first time. It affords this pleasure, even though divested of what is, perhaps, as beautiful to us as the phenomenon itself; we mean the theory which seeks to explain it; for we never regard an experiment, however beautiful, for its own sake, so much as for the assist-

ance it affords in explaining the laws which govern the universe. This feeling is well expressed by the poet Akenside.

> For man loves knowledge, and the beams of Truth
> More welcome touch his understanding's eye,
> Than all the blandishments of sound his ear,
> Than all of taste his tongue. Nor ever yet
> The melting rainbow's vernal tinctured hues
> To me have shown so pleasing, as when first
> The hand of science pointed out the path
> In which the sun-beams, gleaming from the west,
> Fall on the watery cloud, whose darksome veil
> Involves the orient.

12. The colours, which are reflected from the upper surface of the soap-bubble, are caused by the decomposition of the light which falls upon it. If we suppose white light to be composed of the three primitive colours, red, yellow, and blue, (as explained in the paper on the Prism, 77,) and if only one of these colours pass through the film, it follows that two of the component parts of white light remain to be reflected. Again, if two of the colours pass through, the one is reflected. Suppose, for example, that we examine the well defined green part of one of the segments; it is clear that two colours out of the three are reflected, *i. e.*, yellow and blue, (since these two colours combine to form green,) and one colour, viz., red, passes through, or is transmitted. So long as absorption is to be considered as one of the processes which light undergoes, these statements would not perhaps be strictly true; but it is one peculiarity of the class of phenomena which we are now examining, that absorption does not enter into the consideration of the effects produced, the whole being the result of reflexion and transmission. That those rays which are not reflected are transmitted, admits of direct proof; for if we look on the under surface of the film, we shall find that exactly beneath the green we get red: if we look at the reflected red, we shall find green immediately below it. These colours are called *complements* of each other, because all three when combined produce white light, as has been just shown.

13. Should the student find any difficulty in deciding that the superposed colours are really complementary, (and to determine this fact by means of the film is not always easy, when more than one or two of the orders are present,) he had better reserve his observation until the film contains only the first order of colours, or until it becomes divided into the two white and black portions. In either case, the observation is then easily made, and it will be seen that yellow and red on the upper surface, appear as violet and blueish green on the under surface;

and that white *by reflexion* becomes black *by transmission*, and *vice versâ*. In the one case the white results from entire reflexion and no transmission, while in the other case black by reflexion results from entire transmission*.

14. If homogeneous light, *i. e.*, light of one colour only, and which cannot be decomposed by the prism, be allowed to fall upon the bottle, so as to entirely illumine both surfaces of the film, the segments of the film will be reflected of this colour only, separated from each other by dark spaces where the light is entirely transmittted. The central spot (as at *c*, fig. 1, and at A, fig. 4,) will also be dark from the same cause. On looking at the under surface, the central spot and the dark spaces will become the coloured segments, and the coloured segments will become the dark spaces. The cause has been already explained. (12.)

15. Homogeneous light may be most conveniently obtained by means of a prism, mounted on a stand, and placed in a window where the sun is shining. A spectrum will be formed, with a little management, on the wall of the room opposite to the window, and the bottle can be so raised, as that the film shall be surrounded by one colour only of the spectrum.

16. Upon exposing the film successively to the orange, yellow, green, blue, indigo, and violet rays of the spectrum, similar effects can be observed, the coloured segments of the film always appearing of the same colour as the light incident on the film, and separated by dark segments, which, viewed from beneath, appear coloured, while the coloured segments appear dark. There is, however, one remarkable difference observable in the segments of different colours, which is this: that in the colours which are least refracted, the segments are larger than in those formed by the most refrangible rays. Thus, the first red segment is larger than the first orange segment, and this again is larger than the first yellow segment, and so on to the end, the first violet segment being the least.

17. The writer has proceeded thus far in describing, from his own actual experience, these beautiful phenomena obtained by means of simple apparatus within the reach of every one, in

* As a familiar instance of almost entire transmission, we may remind the student of the appearance of a window, seen from without on a cloudy day; and of the difficulty of discerning objects in an apartment, when the observer is at some distance off on the outside. In the one case, the glass appears almost black, because most of the light incident upon it is transmitted into the room. In the other case, objects are not discerned, because they reflect little light to the observer on the outside. Whereas, at night, when the room is well lighted, and rays proceed from within to without, objects often become inconveniently conspicuous.

order to show how much may be done with slight means by the student who enters heartily into the field of scientific inquiry. We now proceed to extend the range of these phenomena; and in doing so we shall probably have to refer to apparatus of a more costly kind than our bottle of soapy water, which apparatus, though necessary to one who would test the accuracy of the recorded results with rigour, may well be dispensed with by him whose mental riches surpass those of a more worldly kind.

18. The phenomena we have been describing must not be supposed to be new; they were discovered by our own great Newton; and, like all the discoveries of that exalted philosopher, are admirable. We shall here find it desirable to call the attention of the reader again to some statements which were made in the article on the Prism, (28 *et seq.*,) because the due comprehension of the causes of the colours on the soap-bubble depends upon our having clear ideas of the chromatic decomposition of a ray of light. In fact, we shall find it necessary to modify, in some degree, our previously formed opinions of the progress of a ray through any medium.

19. When a ray of light impinges on the surface of any body, it undergoes one of two effects: 1st. It passes into the medium on which it impinges, in a certain direction, which direction it retains throughout the whole of its course through such medium; or 2ndly. It is reflected back from the surface, at an equal angle, on the other side of the perpendicular to the surface. Now, if it were possible to divide such medium into a series of plates, each the ten-millionth of an inch thick; and if these plates were separated from each other by spaces equal to the thickness of one of these plates, and a ray of light were to impinge on the surface of the uppermost plate, this ray would penetrate the surface, but would not keep on constant and undeviating in its progress, through the medium. For example: after a ray of white light had penetrated the first plate, the red portion of it is thrown into such a state, that, were it to meet the second surface, it could not penetrate it, and would therefore be reflected, while the two other component parts, yellow and blue, would penetrate the plates, or, in other words, would be transmitted.

20. In the paper on the Vernier, (32,) we have pointed out how an inch may be divided into 100,000 equal parts, but in the details in which we are now engaged, we have to speak of quantities much more minute. There is certainly no method, in practice, by which an inch can be divided into ten million parts, but we can, by the unerring principles of Geometry, ascertain

the exact thickness of films not exceeding ten-millionths of an inch, and of those parts any exact number may be taken. Grains of powder, too, can be measured, whose diameter is less than the 30,000th of an inch. These measurements are not, of course, performed with the rule, nor are they in general ascertained by the eye; they are inferred from known facts, on principles strictly logical, by the extension of the reasoning powers far beyond the limit of the powers of the outward senses. Indeed, there is nothing more calculated to prove the superiority of mind over body, than the rigid exactness of theoretical science, compared with the inaccuracy of practice. The perfection which theory assumes is, actually, only an approximation to perfection, for perfection belongs only to the Deity Himself; but it is the business of science to make that approximation more and more near. The lower animals often achieve results with a degree of perfection and exactness far beyond our limited mechanical means; but this perfection, which does honour to the Creator, does but little honour to them. They are so perfect, only because their perfection consists in performing with exactness the small part assigned to them in the great scheme of Creation. But to return:—

21. Before we proceed to ascertain the thickness of the soap-bubble, we must premise that Newton was induced, from its evanescent nature, to find some other means of examining the colours reflected by thin transparent films. Glass may be blown so thin as to exhibit these colours; but in this state of extreme tenuity, it is almost as fragile as the soap-bubble itself. Newton therefore adopted the following ingenious contrivance. He procured a plano-convex lens, the radius of whose convex surface was 28 feet; and a double-convex lens, the radius of each surface of which was 50 feet. That is, in the first case, if we suppose a solid globe of glass, 56 feet in diameter, a piece, of any size less than one-half, cut off from it, would form a plano-convex lens, of 28 feet radius; and in the second case, a globe being 100 feet in diameter, a piece, of any size, scooped from out of it, would form a double-convex lens of 50 feet radius, whose convexity, therefore, would be scarcely perceptible if the lens were small.

22. The convex surface of the one lens was placed upon the plane surface of the other, so that the two surfaces were in actual contact at their centres only, the distance between them increasing as the distance from the centre increased. These lenses were mounted in a frame, and by means of screws were pressed together with any degree of force required. The mode of fixing these lenses was as follows: the two lenses were superposed, the

double-convex lens being placed on the plane surface of the plano-convex lens; the lenses were in contact at their centres, but apart at their edges. Three screws are then attached to the lenses, with small disks of cork, leather, or cloth, between the ends of the screws and the glass. By means of these screws the lenses can be pressed closer together; a sufficient proof, in itself, that the lenses are never in absolute contact, even when the senses are unable to appreciate any distance between them. Thus a film of air was enclosed between the two lenses, which film was plane on one side and concave on the other, and devoid of thickness at the centre, where the two lenses were in a state of greatest approximation: so that, for all practical purposes the air is devoid of thickness at the middle;—the rigour of modern science, however, requires us to believe that absolute contact, in the strictest sense of the word, is unknown. Fig. 2 shows the above arrangement, and fig. 3 shows the two lenses in section; the proportion of the curvatures being, of course, much exaggerated in the latter figure, in order to show the gradual increase in the thickness of the film of air.

Fig. 2.

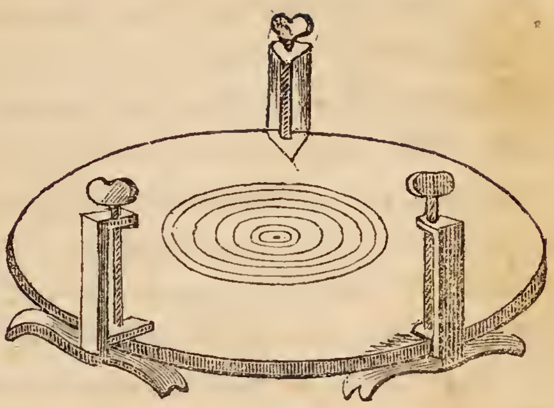
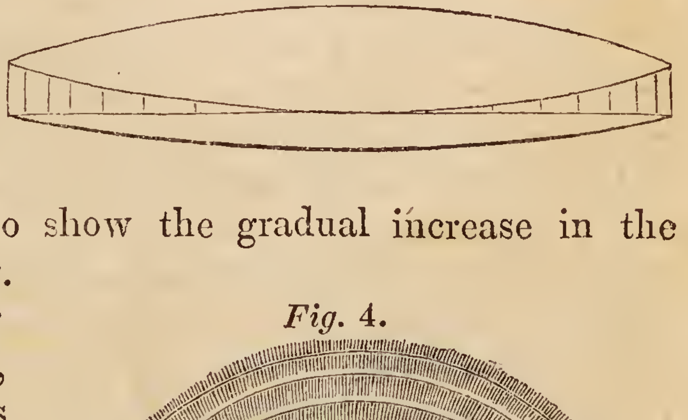


Fig. 3.



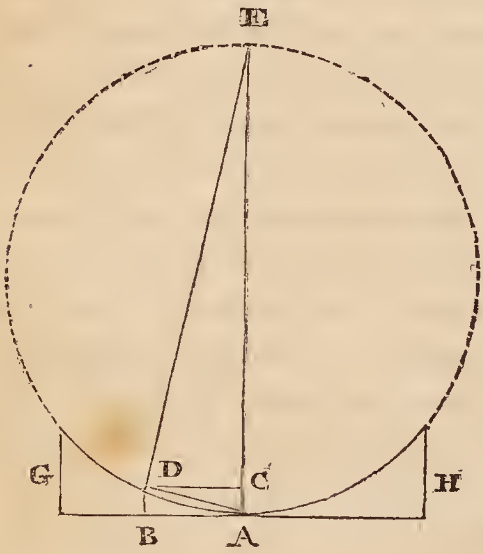
23. Upon exposing these lenses to the light, coloured concentric rings were observed, the centre being the point of contact, and this was a *black spot.* The annexed figure, (fig. 4,) to which we shall refer presently, will assist in explaining the formation of the rings. It is intended to represent the front view of the central portion of fig. 3. The central black spot, A, fig. 4, is the point

Fig. 4.

of contact at the centre of the lenses, round which the seven orders of coloured rings are seen.

All the other phenomena, which we have already described, can also be obtained by means of these lenses. There are other circumstances attending their production, to which we shall refer, after having shown how the thickness of the air-lens can be determined. In doing this, we shall depart somewhat from our general plan, and enter to a small extent on geometrical reasoning. A slight knowledge of that beautiful science will, however, be sufficient to enable the student to follow our details.

Fig. 5.



24. Let G H, fig. 5, be the convex lens of air formed between the two lenses of glass. Let the radius of its concave surface be 50 feet. Suppose now that it be required to find the thickness, B D, of a ring whose radius is A B. This radius is found by measuring from the centre, A, (fig. 4,) to one of the circles, A^1, A^2, or A^3, by means of a delicate instrument; and we will assume it to be one-quarter of an inch. By drawing the chords A D, D E, we get a right-angled triangle, A D E; because, as Euclid teaches, B. 3., Prop. 31, every triangle within a semi-circle, if the apex touch the arc, and one of the sides be the diameter, is a right-angled triangle, and the angle at the apex is the right angle. In like manner we shall obtain two other right-angled triangles, A C D, and E C D, by drawing the line C D, perpendicular to A E, and therefore parallel and equal to A B. The two triangles, A C D, and C D E, are similar, as Euclid shows, B. 6., Prop. 8. Hence, in two similar triangles, (that is, two triangles of which all the angles of the one are respectively equal to all the angles of the other, each to each,) the ratio existing between the sides of one triangle corresponds with the ratio existing between the sides of the other. In our figure, therefore, the line C E bears the same proportion to C D, as C D does to C A, or to D B, which is the thickness required. But as A C is exceedingly small, compared with A E, this latter may be accounted as nothing, and therefore A E and C E are for all practical purposes the same. So that, as A E or C E : C D : : C D : C A or B D; or, as 100 feet : $\frac{1}{4}$ in : : $\frac{1}{4}$ in : $\frac{1}{19200}$th of an inch, the thickness of the air-lens at B D.

25. As this is an exceedingly beautiful, and at the same time simple, example of the application of mathematics to physical phenomena, the reader who is desirous of catching a glimpse of the admirable tools with which the man of principles, in contradistinction to the man of mere facts, works, he will do well to calculate for himself a few such examples as the following.

It is required to find the thickness of a ring whose diameter is two-thirds of an inch, the focus of the double-convex lens being 40 feet. As the focus is equal to the radius, (the index of refraction of the glass being 1·5), the radius must be 40 feet, and the diameter 80 feet. The diameter of the ring being assumed as $\frac{2}{3}$ of an inch, that makes the radius A B, or C D of the ring $=\frac{1}{3}$rd of an inch; then,

As 80 feet : $\frac{1}{3}$rd of an inch : : $\frac{1}{3}$rd of an inch : $\frac{1}{8640}$th of an inch, the thickness required.

Again, suppose the double-convex lens employed has a focus of 35 feet, and it is required to find the thickness of a ring whose diameter is found by measurement to be 0·2712 of an inch. Then radius = 35 feet, ∴ diameter = 70 feet; and the radius A B or C D of the ring = 0·1356 of an inch.

As 70 feet : 0·1356 inches : : 0·1356 inches : 0·00002189 nearly, which is the thickness required.

It will be remembered that the concave surface, G H, in fig. 5, is much exaggerated, and that the three examples just given, are calculated on assumed data; which, however, do not at all affect the accuracy of the principle which we have been endeavouring to illustrate.

26. The colours of thin plates or films depend, therefore, upon *thinness* alone, and not upon material; for the colours between the lenses can be seen *in vacuo*. Sir Isaac Newton found that by allowing a drop of water to insinuate itself between the glasses, the lens being now of a more refractive power than air, the diameter of the rings was contracted; that is, that the same colour was produced at a less thickness, and this exactly in proportion to the refractive power.

27. Newton calculated the results which he obtained with great exactness. He computed the thickness of his air-lens at different parts by a process such as we have before shown, and then, by observing what colour was reflected at a certain distance from the centre of the lenses, he was enabled to form a complete table of colours with their respective thicknesses. *Air*, at, and below a thickness of $\frac{1}{2}$ a millionth of an inch, no longer reflected light; at, and above a thickness of 72 mil-

lionths, it reflects white; and between those two limits, it reflects the several orders of colours. *Water*, at, and below a thickness of $\frac{3}{8}$ of a millionth of an inch, ceases to reflect light; at, and above 58 millionths, it reflects white; and between those two limits, it reflects all the several orders of colours. *Glass*, at, and below a thickness of $\frac{1}{3}$ of a millionth of an inch, ceases to reflect light; at, and above a thickness of 50 millionths, it reflects white; and between those limits, all the intermediate colours are reflected.

28. In the following table, the various gradations of colour, and the thicknesses of the lens upon which those colours depend, are minutely detailed for reflected light, when the rays fall perpendicular to the plane surface of the air-lens. When the incident ray enters the air-lens obliquely to its surface, it will be reflected at the same obliquity. The rings in this case increase in size, the same colour requiring a greater thickness to produce it. In plates of mica, &c., the effect of obliquity is very apparent: a colour, produced by the reflexion of perpendicular rays, descends in the scale to one of a lower order, in proportion as we deviate from perpendicularity. The reason is, that we look through a greater thickness in an oblique than in a perpendicular direction. When the thin plate or film is of a rarer material than the surrounding air, it will reflect various shades of colour according to the angle of obliquity; but, if the plate be denser, the colours are not much changed by a variation of obliquity.

TABLE OF THE COLOURS OF THIN PLATES OF AIR AND WATER,
In thicknesses of Millionths of an Inch.

Colours reflected.	The same colours compared with natural objects.	Thickness of the stratum of Air.	Water.
FIRST SERIES.			
Deep black		0·50	0·38
Black		1·00	0·75
Beginning of black		2·00	1·50
Blue	A whitish sky-blue	2·40	1·80
White	Purified silver	5·25	3·88
Yellow	Straw	7·11	5·33
Orange	Dried rind of orange	8·00	6·00
Red	Geranium sanguineum	9·00	6·75
SECOND SERIES.			
Violet	Iodine-vapour	11·17	8·38
Indigo		12·83	9·62
Blue	Cobalt	14·00	10·50
Green	Sea-water	15·12	11·33
Yellow	Citron	16·29	12·20
Orange	New oranges	17·22	13·00
Bright red		18·33	13·75
Crimson red		19·67	14·75
THIRD SERIES.			
Purple	Flower of Lint	21·00	15·75
Indigo		22·10	16·57
Blue	Prussian	23·40	17·55
Green	Lively grass-green	25·20	18·90
Yellow	Planed deal	27·14	20·33
Red	Couleur de rose	29·00	24·00
Blueish green		32·00	24·00
FOURTH SERIES.			
Blueish green		34·00	25·50
Green	Emerald	35·29	26·50
Yellowish green		36·00	27·00
Red	Dog-rose	40·33	30·25
FIFTH SERIES.			
Greenish blue	Sea-green	46·00	34·10
Red	Pale rose	52·50	39·38
SIXTH SERIES.			
Greenish blue		58·75	44·00
Red	Light rose	65·00	48·75
SEVENTH SERIES.			
Greenish blue		71·00	53·25
Reddish white very pale		77·00	57·75

After the seventh order, the colours become too faint to be distinguished, in consequence of the thickness of the air-lens.

The breadths of the rings are very unequal. They decrease, and the colours become more crowded, as they recede from the centre. Newton found by actual measurement, the diameter of the darkest or purple rings, just when the black spot began to appear by pressure, reckoning it as one of them, to be as the square roots of the even numbers, 0, 2, 4, 6, 8, &c.; and those of the brightest parts of the several orders of colours, to be as the square roots of the odd numbers, 1, 3, 5, 7, &c. So that there is a very simple ratio existing between the thicknesses of the air-lens, at which the bright and dark colours succeed each other.

29. These proportions apply whether the light be white or homogeneous; although, in the latter case, the magnitudes of the rings is different with light of different colours. If we suppose an inch to be divided into 180,000 equal parts, and at a thickness of one of those parts a green ring to appear, (the lens being illumined by green light), at a thickness equal to two of those parts there will be a dark ring: at a thickness equal to three of them, another green ring, and so on alternately.

30. Since each homogeneous colour forms its own set of rings, it naturally follows that seven systems are produced by employing white solar light. In speaking of the prism, we stated (59) that Newton concluded from the phenomena presented to him, in the course of his experiments, that light of each colour had a refractive power belonging to itself. It has, however, been shown by Sir D. Brewster, that all the three primitive colours exist at every part of the spectrum, in greater or less proportions. Thus, at the lower end of the spectrum red is most abundant, while the yellow and blue exist in very small proportions. In the yellow space there is red and blue also; but the maximum is yellow. Between the red and yellow we find orange, formed by the superposition of red, yellow, and blue; but the latter colour exists in so small a quantity, that its effect is scarcely perceived. Between the yellow and blue, green is formed by the superposition of yellow and blue; and indigo and violet are formed by various admixtures of blue and red. In this way seven colours (three simple, and four compound) are produced in the order previously stated, viz., red, orange, yellow, green, blue, indigo, and violet. So also with the rings: those of one colour intermixing with the colours of others, form the several orders already pointed out. These views have been suggested to Sir D. Brewster by the results of a train of experiments on the absorption of light, when passing through various media. (See PRISM, 87.)

31. We have hitherto confined our attention to the co-

loured systems belonging to the soap-bubble, and to the air-lens. These are, however, only individual instances. Many others occur to our daily observation, and many more might be devised by a moderate exercise of ingenuity. For instance: the late Professor Ritchie devised an ingenious mode of showing the colours of thin plates, by taking two pieces of perfectly parallel glass, and placing their surfaces together with a narrow slip of leaf-gold between them, extending inwards about half an inch from the edges of the glasses. Thus, the centres of the two glasses were separated from each other by a stratum of air not more than $\frac{1}{180000}$th of an inch in thickness. By applying a screw to the exterior surfaces of both glasses, he could bring the centres into contact; by which a series of rings, such as we have before described, was formed round the point of contact.

32. Most persons have witnessed the effect of heating the blade of a knife in the fire or in the candle. The yellow or blue appearance which results, is due to a thin film of oxide formed on its surface; for if the steel be heated *in vacuo*, or in a gaseous medium which contains no oxygen, the colours do not appear. The blueness of the steel with which the mainspring of a watch or chronometer is formed, is also due to the same cause. Cracks in glass often exhibit these colours; also certain laminated minerals, such as Iceland-spar, talc or mica, hornblende, selenite, &c.; also window-glass that has been much exposed to the weather. A drop of oil spread on the surface of water, or liquids spread in very thin layers on surfaces of glass, become iridescent, or *rainbow-like*, as they evaporate. Silver leaf, if the book in which it is contained be not carefully kept from the air and damp, will become tarnished at the edges, in consequence of a thin film of oxide being formed on the metal. We have a piece of silver affected in this way, in which the colours are of the most glowing brilliancy, the hue changing as often as the thickness of the film of oxide changes. All these substances become coloured from the same causes as the soap-bubble and the air-lens.

33. Iridescence of mother-of-pearl is another beautiful instance of the same phenomena, depending upon a peculiarity in the structure of that substance. The surface, which to the eye and touch appears to be finely polished, contains, nevertheless, a large number of grooves, in some places as many as 3000 within the space of an inch. These grooves are parallel, and follow each other regularly in all their curvatures, by the edges of which the rays of light are reflected, and the frequent change of colour arises from their frequent bendings. That

such is the case, may be proved by taking a wax impression of the surface; the impression will show a play of colours similar to the mother-of-pearl itself. Grooves have been cut on the surface of glass, and on various metals, so as to produce the same effect. These grooves are so fine as to be scarcely visible without the aid of a microscope, and the glass or metal appears to retain its polish. Buttons, and other ornaments, (called *Iris*-ornaments, from their reflecting all the gorgeous hues of the *iris*, or *rainbow*,) have been thus formed, which in a strong light are of extreme beauty.

34. Such, then, being the optical properties of minute films, the colours being produced and succeeding each other in a determined and well ascertained order, and the thicknesses necessary to produce such orders of colours by reflexion being also known—it follows, that we can measure the minute thicknesses of transparent bodies by their colours, when all other methods of measurement would entirely fail.

35. It will be seen, then, that the colours produced by thinness, (hence called the *colours of thin plates*,) depend upon this property alone, and have little relation to the nature of the substance which composes them. If we could go on diminishing, by art, the thickness of a given body, we should at length arrive at a thickness where the light would be coloured both by reflexion and transmission. For example, we all know that gold is an opaque body; yet it may be reduced to such a degree of tenuity, as to become translucent, or semi-transparent. Leaf-gold is not more than $\frac{1}{180000}$th of an inch in thickness; and if we hold up a piece of such gold between the eye and the light, we shall perceive it of a green colour; that is, although gold be considered to be an opaque body, yet, when reduced to such thinness, it allows green rays of light, or such rays as form green, to pass through it. If we could proceed in the process of attenuation, we should arrive at another point where the film would appear entirely *black* by reflexion, and white by transmission,—whatever the material of the body might be. This has never yet been done artificially in a solid body; but accident once effected what art could not accomplish. A quartz crystal, about $2\frac{1}{4}$ inches in diameter, was broken in two. The two surfaces of fracture appeared absolutely *black*, like dark velvet, and the sable hue appeared, at first sight, to depend upon a thin film of minutely divided opaque matter, which had insinuated itself at a crack in the stone. Upon examining the crystal, however, by various optical means, Sir D. Brewster found that the surface was perfectly transparent by transmitted light; and

that the blackness arose from the circumstance of the surfaces being composed of a fine down of quartz, or of short slender filaments, whose diameter was so exceedingly small that they were incapable of reflecting a single ray of the strongest light. The diameter of any one of these fibres could not exceed one-third of the millionth part of an inch; otherwise the surface could not be black by reflexion. Sir D. Brewster remarks, "I have no doubt that fractures of quartz and other minerals will yet be found, which shall exhibit a fine down of different colours, depending on their size."

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36. We come now to notice an entirely new mode of producing Newton's rings, and the colours of thin plates, which mode has recently been discovered by the author of this work. In pursuing this mode, the student may employ himself, with no fear of exhausting the subject. The colours produced by the plan about to be stated are so lovely;—the method of their production so extraordinary;—the variety in the results so great;—and all so compatible with the means possessed by every student in science, that we recommend him to verify the following experiments, and to extend them to a larger variety of fluid substances. The theory of these results, so far as it relates to the colours of thin plates in connexion with the phenomena already described, we shall give presently; but the theory of *most* of the following experiments is not yet announced;—it is new and peculiar; and will therefore be fairly open to discussion elsewhere. For this reason, the author will here content himself chiefly with describing facts, about which doubt is not so likely to exist.

The facility with which oil becomes diffused over the surface of water, is well known; and, among the oils, that of turpentine displays extraordinary facility. Animal and vegetable oils, fluid balsams, varnishes, essences, and those fluid substances, generally, which do not dissolve in water, are well adapted to the present inquiry. Some of the oils and balsams, such as castor-oil and Canada balsam, are too viscid at the ordinary temperature to spread out into films. The spreading out of a drop of oil into a film upon the surface of water, we shall call *diffusion*. Now this diffusion is in all cases promoted by heat—a viscid oil, if heated to 300° or 400°, becomes as limpid and fluid as water; and a drop of it can thus be readily diffused over the surface of water.

A single drop of oil, &c., is thus sufficient, in general, to form

a circular film, of from two to five inches in diameter. Now, whether this film will reflect the colours of thin plates, depends upon its thickness. We will first instance a film which does *not* reflect colour.

37. A glass-full of clean, still water, being placed before the window, and the head of the observer so inclined as to get an uninterrupted view of the light reflected from the surface of the water, which is, of course, between the window and the observer—let a clean glass rod be dipped into oil of turpentine, and let a single drop of the oil, hanging from the end of the rod, fall upon the centre of the surface of the water from a height of about $\frac{1}{2}$ an inch:—the drop will be immediately diffused into a film, which reflects white light only.

38. If we now wet the finger thoroughly in sulphuric ether, and hold it a distance varying from $\frac{1}{2}$ to $\frac{1}{8}$th of an inch over the film, taking care neither to touch the film nor to drop ether upon it, we instantly see a repulsion or recession of particles; a black spot is formed, and round it the seven orders of rings appear in all their lustre and beauty. The diameter of the rings depends upon the quantity of ether upon the finger, the rapidity of evaporation, and the proximity of the point of the finger to the film. Upon these circumstances, too, it depends whether the seven systems, or a less number, be developed:—if a less number, the central colour is *not*, of course, *black;* but one of the colours lower down in the scale. If the repulsion be very strong and decided, the black spot may be as large as $\frac{1}{2}$ or $\frac{3}{4}$ of an inch in diameter. The rings remain just so long as the finger is wet with ether, which having evaporated, or the wet finger being removed, the rings contract in diameter, and disappear altogether. These rings can be formed at any part of the surface of the film; and any number of times, while the film endures.

39. This experiment cannot fail to attract the notice of any one observing it for the first time. The author was led to its discovery by theoretical reasoning, into which he needs not now enter. To produce the results shown above, certain precautions, and a delicacy of manipulation, are necessary: it may not, therefore, be thought tedious, if the author state fully, the precautions necessary to success. 1. The glass and the water must be perfectly clean and free from grease. 2. The glass of water must stand before the light, so as to reflect it; and the surface of the water must be perfectly tranquil. Any shaking of the room, or of the table, will tend to break up the film, and spoil the experiment. 3. A clean glass rod must be dipped into the oil, and a single drop only must be placed upon the surface of the water.

If a second drop escape, it will fall upon the film formed by the first drop; and will rest for some time as a globule upon this film without coalescing, which it will at length do only in part. It then breaks up the first film, or renders it too thick for the purposes of experiment. 4. The ether must be held *over* the film, but *not* allowed to touch or drop upon it,—if such be the case, the film is destroyed. 5. The finger wetted with ether must be clean, and the ether be carefully excluded from contact with oil.

The finger dipped in ether seems preferable to anything else for developing the rings. If a glass rod be dipped in ether, the hanging drop is liable to fall with the slightest agitation, so that a piece of porous wood, a camel's hair pencil, &c., may be used, and will answer the purpose very well; but, if any substance be employed which has not a pointed or circular termination, the rings will not be formed; and there will only result a series of concentric figures, depending for form upon that of the end of the substance held over the film.

40. If, instead of dipping the finger in ether, we employ liquor ammoniæ, pyroligneous ether, alcohol, or naphtha, similar effects are produced upon the film, and in a manner more or less decided than with ether. It sometimes happens that a drop of strong solution of ammoniacal gas held over the film produces so energetic a repulsion, that the film is instantly broken up, and scattered about in all directions over the surface of the water.

41. Oil of turpentine, as we said, affords a colourless film; and no colour can in general be observed upon it, (except by means of the ether, &c.,) until, after the lapse of several minutes, evaporation has so far diminished the thickness of the film, as to produce the colours, which are instantly recognised as the colours of thin plates. But these colours appear of indefinite forms, in consequence of the unequal thickness of the film at different parts. Hence, we cannot preserve a colourless turpentine-film many minutes: and as it is often desirable to preserve a film for a considerable time, which film shall exhibit no colour except when subjected to the action of the ether, &c., we may employ a drop of the fixed oils of olive, rape, castor, nut, &c., instead of the volatile oil of turpentine.

Now it is frequently desirable to test the action of the ether, &c., 1st, upon a film colourless in the first instance, but soon after coloured in consequence of evaporation: 2nd, upon a film which remains colourless for a considerable time: 3rd, upon a film which exhibits colour in the first instance: and 4th, upon a drop of oil on the surface of water, which drop is not diffused into a film.

The *first* we may obtain from turpentine, and the *second* from some of the fixed oils; we now proceed to notice the action of the *third*.

If a drop of balsam of Peru, or of one of the turpentine-varnishes, such as the druggist calls copal-varnish, carriage-varnish, gold size, black japan, &c., be placed upon the surface of water with the same precautions as before, two or three superb systems of rings are instantly formed, the diameter of the external ring often approaching that of the glass vessel containing the water. If we now apply the ether to any part of the surface, we immediately get a series of rings as before, quite independent of the large rings which occupy the surface of the water. That part of the film subjected to the action of the ether no longer forms a portion of the original film, but is subject to the systematic arrangement which the ether produces. A film, showing the colours of the 5th, 6th, and 7th orders only, is at that particular part which is subjected to the action of the ethereal vapour, made sufficiently thin to exhibit, in a systematic order, the rings of the 1st, 2nd, 3rd, and 4th systems, or of the 2nd and 3rd, or of the 3rd and 4th, all depending upon the quantity of ether collected upon the finger, the rate of evaporation, and the proximity of the finger's point to the film. The colours afforded by the film of balsam of Peru, and of black japan, are so superb and glowing, that any attempt at description or comparison must fail.

An oil or balsam, which is naturally viscid at the ordinary temperature of the air, such as castor-oil or Canada balsam, may be employed, when a drop instead of a film is required upon the surface of water. Essential oil of cloves, as sold by the druggists, is also favourable for this purpose. It is generally retailed in an adulterated form by being mixed with a cheaper oil, such as olive-oil. Now, as the essential oil is heavier than water, the fraud may be detected by dropping it in water; the oil sinks, and the greater portion of the olive-oil separates and rises to the surface; but there is no diffusion. If the ether be presented to the drop so collected, it will be powerfully repelled; and can thus be driven with great energy over the surface of the water.

42. The repulsive effects upon films, as noticed with ether, ammonia, &c., may also be extended to powders. If a small quantity of protoxide of mercury be scattered on the surface of water, the greater portion of it will sink to the bottom; but the smaller particles will float, and form a film which is subject to strong repulsion from the vapours of the before mentioned liquids. Turpentine and some of the volatile oils produce

a similar effect upon powders; and one volatile oil frequently repels a film formed by another.

43. If the ether be presented to the surface of pure water only, the repulsion or recession of particles can be seen; and a cup-shaped cavity with a perfectly well defined edge is formed, When a drop of ether is placed upon the surface of water, there is a considerable commotion and agitation; and the ether is soon diffused in a thin layer over the water without combining with it.

44. We have hitherto spoken of the *repulsion* of films and powders. A strong and decided *attraction* may be exhibited by presenting to the film a drop of an acid whose boiling-point is low; such as nitric or pyroligneous acid. By such means an oil-film, of the size of a crown-piece, may be reduced to the size of a sixpence; and a film, exhibiting colour, will have all colour destroyed by the proximity of the acid, whose influence is to thicken the film. Sulphuret of carbon and an aqueous solution of chlorine produce a similar effect.

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45. iii. We now proceed to a brief exposition of Newton's theory of the colours of thin plates. Ingenious and beautiful as it is, yet, as it rests upon an uncertain basis, which the discoveries of our own times are undermining, we shall confine our details within narrow limits. Newton himself distinctly declares that the theory, which explains these phenomena, is merely a hypothesis of his own, without deciding whether it be true or false. He supposes, then, that every particle of light, from its first discharge from a luminous body, possesses, at equally distant intervals, the property of being easily reflected from, or easily transmitted through, the surfaces of bodies upon which such light is incident. This property he terms, *Fits of easy reflexion and transmission*. If, for example, a particle of light, when in its fit of reflexion, reach a reflecting surface, it will yield readily to the reflecting force of this surface; but if it be in a fit of transmission, it will not yield to the reflecting force.

46. Sir D. Brewster, without giving it as a theory, suggests the following mode of illustrating the nature of this property; by imagining that the particles of light have two attractive and two repulsive poles, at the extremities of two axes at right angles to each other; and that the particles revolve round their axes, and at equidistant intervals bring one or other of these axes into the line of the direction in which the particle is moving. If the *attractive* axis be in the line of the direction in which the

particle moves when it reaches the refracting surface, the particle will yield to the attractive force of the medium, and be refracted and transmitted; but if the repulsive axis be in the direction of the particle's motion when it reaches the surface, it will yield to the repulsive force of the medium, and be reflected from it.

47. Sir J. Herschel illustrates the nature of this assumed property of light by supposing every particle of light to be a sort of little magnet, revolving rapidly about its own centre, while it advances in its course; thus alternately presenting its attractive and repulsive pole; so that, when it arrives at the surface of a body with its repulsive pole foremost, it is repelled and reflected; but, when it arrives at the surface with its attractive pole foremost, it is attracted and transmitted.

We may take either of these modes of illustration, and apply it to the phenomena observed. When light falls upon the plane surface of the air-lens, G H, fig. 5, such rays as are in a fit of reflexion are reflected, and those that are in a fit of transmission are transmitted. The distance through which the particle of light moves, while it passes from a fit of reflexion to a fit of transmission, may be called the *length* of the fit. Since all the particles of light were in a state of easy transmission when they entered the plane surface of G H, it is clear that, if the thickness of the air lens at A be less than half the length of the fit, the particles of light do not cease to retain their fit of transmission, but pass through the thickness at A, in the state of transmission. None of the light therefore being reflected, we get the black spot at A, fig. 4. When the air-lens becomes thicker, towards B, fig. 5, and A 1, fig. 4., so that its thickness exceeds half the length of the fit, the light will not reach the concave surface of the lens G H, before it has passed into a fit of reflexion, so that at A 1, fig. 4, the light will be all reflected and none transmitted. In this way at A 1, A 3, A 5, and A 7, fig. 4, the light will be reflected; while at A, A 2, A 4, A 6, it will be transmitted.

In this illustration, we have supposed the light to be homogeneous; because the results so afforded admit of a simpler adaptation to the theory. If the light be, as it generally is, white, then the variously coloured fringes form, by their superposition, a system of fringes similar to those detailed at length in the table of the colours of thin plates. (28.)

48. This hypothesis is deduced from Newton's own theory of light, viz., the *corpuscular* theory, which supposes light to consist of atoms, termed *corpuscules*, or *little bodies*, projected from the luminous body into space, and moving with a velocity of 192,500 miles during a second of time, which velocity was

deduced by Römer, in the manner described in the article on the Prism (10). The more modern, and perhaps, more favoured theory, viz., the *undulatory*, supposes light to consist of an exceedingly thin, elastic, medium, called *ether*, which is supposed to fill all space and to occupy the intervals between the particles of matter. This ether is supposed to vibrate in a manner similar to air; the result of the vibration of the first being *light*, and of the second *sound*. In both cases the *waves*, or vibrations, can be propagated in all directions: which waves, in the one case, meeting the nerves of the eye, excite the sensation of light, and in the other case, reaching the nerves of the ear, excite that of sound. The corpuscular theory of light accounts for the production of colour, by supposing a property inherent in the coloured body, of absorbing certain rays and reflecting others: while the undulatory theory supposes that difference of colour arises from differences in the frequency of the ethereal undulations. It has been calculated that the extreme red of the spectrum is due to 458 millions of millions of vibrations per second; while to the extreme violet rays are assigned 727 millions of millions of vibrations in the same time. The other colours are due to numbers of undulations intermediate between these two extremes.

49. In the paper on the Harmonica, (16,) we explain briefly how sonorous waves, by interference, produce either silence or an increased tone. This doctrine will apply also to light. If we suppose two pencils of light to proceed from two points, very near each other, and the light from both points to fall upon the same spot of a sheet of paper held parallel to the line joining the points, this spot will be illuminated with the sum of the two lights, and it will be found that the bright spot on the paper is equally distant from both the luminous points. Now, in the case of two sonorous bodies, each vibrating 100 times per second,—if both vibrate together, a sound will result of double the intensity of one body vibrating alone; but if one of these bodies vibrate 100 times in a second, and the other 108 in the same time, the forward advance of the waves from each is the same at the beginning of their vibratory action; but at the end of six seconds, the more rapidly recurring vibrations of the second body, have so far gained upon the slower vibrations of the first, that the progressive motion of the air from one is nearly equal to the recessive motion from the other; and thus it is that the two vibrations destroy each other, and produce an interval of absolute silence.

Now, to apply this analogy to the bright spot on the sheet of paper:—We have said that this spot is equidistant from the two

luminous points. Now, if there be a certain difference between the lengths of the paths of the two pencils of light, and if we call this difference 1, 2, 3, 4, &c., the bright spot will remain as the sum of the two pencils of light; but if this difference be $\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$, $3\frac{1}{2}$, &c., the two pencils of light, instead of adding to each other's intensity, actually destroy each other, and produce a dark spot instead of a bright one.

These cases, both in sound and in light, belong to the doctrine of *interference;* which theory well accounts for the colours of thin plates. It is supposed that the light reflected from the concave surface of the air-lens G H, fig. 4, interferes with the light reflected from the plane surface; and, as these two pencils of light come from different points of space, they reach the eye with different lengths of paths. Hence they will, by their interference, form luminous fringes when the difference of the paths is 1, 2, 3, 4, &c., and dark fringes when the difference is $\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$, $3\frac{1}{2}$, &c. Thus, in fig. 4, the luminous rings will be at A 2, A 4, A 6, &c., and dark rings at A 1, A 3, A 5, &c.

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50. iv. It is always instructive and interesting, when we can bring the phenomena of one science to bear upon and explain those of another. The undulatory theory of light owes much of its beauty to the facility with which the laws regulating sonorous vibrations, become adapted to the explanation of optical phenomena. The strong analogies, which are being constantly discovered between one science and another, show us how little Nature regards arbitrary distinctions. We will give an interesting example of the adaptation of Newton's rings to the elucidation of what is termed the *repulsive property of heat.*

51. The expansion of bodies by heat seems to imply a mutual repulsion of their atoms at insensible distances; and it has been a question whether such a repulsive power does not belong generally to heat, and whether it cannot be made apparent at sensible, as well as insensible distances.

The nature of the question will be immediately understood, by supposing a rod of steel (any substance will do) to have, at a temperature of 32°, a length which we will call 1·000000. By raising its temperature to 212°, the rod of steel becomes 1·001189 in length. But this rod of steel is not altered (so far as we know) by this change of temperature, except slightly in its dimensions;—the atoms which compose it (and these, in the present state of our knowledge, far exceed the power of human calculation to number,) are supposed to be farther apart than they were before;

although, when subjected to the severest scrutiny, they still appear to us to be in absolute contact; and it is only by snapping the bar of steel asunder, that we are capable of deciding upon the separation of any of its parts. The point, then, to ascertain is, whether, if this repulsive property exists in heat, it produces a separation between the particles of matter sufficiently great to be measured.

52. This difficult question has engaged the attention of many eminent philosophers; and none seem to have succeeded, until it occurred to the Rev. Professor Powell to employ the air-lens, formed between the two glass lenses, in the following manner. Having produced the coloured rings by the permanent pressure of the two lenses, heat was applied at C or A, fig. 4, when the rings immediately began to contract, and the central tint descended in the scale, *i. e.*, from first order to second order, from second to third, and so on: thus indicating a greater thickness of the lens at C for each advance. This continued, until all the rings vanished. Hence, it was concluded, that the separation of the glasses through the extremely small, but finite and known spaces, whose changes are indicated by the degradation of tints, can only be due to the real action of a repulsive power, produced or excited between the surfaces of the glasses by the action of heat.

53. There is another striking experiment, discovered by Leidenfrost, in 1756, which seems to prove the existence of a repulsive force between heated bodies, which force augments with their temperature. If a polished metallic vessel, such as a platinum crucible, be brought to a red or white heat, and several drops of water be allowed to fall into it, they unite into a globule, which spins rapidly round without ebullition, and evaporation is slow in proportion as the temperature of the vessel is high. It is necessary to the success of this experiment, that the globule, whether from a calorific repulsion or any other cause, be not in contact with the heated metal; and accordingly we find that if the vessel be removed from the source of heat, and allowed to cool down to a certain point, a portion of the water flashes into steam by coming into contact with the heated metal. The author of this work has found that these phenomena apply also to ether, alcohol, mercury, and many saline solutions; but not to oils. He has also varied the experiment by employing a fixed oil at the temperature of 450° or 500°, instead of the heated metal. When turpentine is dropped upon it, it forms a disk, with a perfectly well defined edge; the disk rotates rapidly in a horizontal plane, and soon disappears by evapo-

ration. If several drops of sulphuric ether be placed upon the heated oil, they unite and form one large globule, which appears to be a perfect sphere:—this rotates with great rapidity upon its axis, and moves rapidly over the surface of the oil. If now, we place a drop of water upon the heated oil, it will form a similar figure to the ether, and behave in the same manner for an instant or two, so that it will not be possible, by inspection, to distinguish the globule of ether from the globule of water. Now, the most important point of this experiment is, that when the two globules get within the sphere of each other's attraction, that is within an inch, or an inch and a half of each other, a powerful attraction is manifested; the two globules bound up against each other, unite, and form one drop which continues to rotate until it disappears by evaporation; or, as it sometimes happens, the drop, formed by the union of ether and water, sinks below the surface of the oil, bursts into vapour, and scatters the oil about with considerable force. Hence, much caution is required in conducting this experiment. In some cases, however, when the globule sinks below the surface of the oil, an equable atmosphere of vapour is formed around it; so that, becoming specifically lighter than the oil, it is instantly thrown up again to the surface without bursting into vapour; and it continues to rotate on the surface of the oil as before.

In this experiment we find these remarkable facts; 1st, that a drop of so volatile a liquid as ether is capable of resting upon the surface of oil at the temperature of 400° or 500°, without evaporating much more quickly than a similar drop would do if exposed upon a surface at the ordinary temperature of the air; 2nd, that water, whose specific gravity is far greater than that of hot oil, rests upon such oil, and moves about with great rapidity; 3rd, that, under these circumstances, ether and water appear to unite with considerable force. It is, however, highly probable that the union is mechanical and not chemical. If drops of water, coloured with ink, be placed upon the hot oil, considerable agitation can be perceived within the watery globule, when it unites with the ethereal globule. The ether appears to occupy the upper part of the watery globule, or to encompass it entirely, in which latter case two concentric spheres are formed: the inner sphere, of water, is considerably agitated; and the particles of colouring matter move about within it with considerable rapidity; but the surface of the globule shows no agitation whatever; nor can evaporation be appreciated therefrom, except by noticing its slow and gradual diminution in size.

Alcohol, pyroligneous ether, naphtha, and bi-sulphuret of car

bon, form globules on the surface of hot oil; which globules behave in the same manner as sulphuric ether. Ether also forms a rotating globule on the surface of hot water and mercury.

If sulphuric acid be heated to about 400°, and ether be placed on the surface, it forms globules which dart about with astonishing rapidity; alcohol also forms globules; but naphtha and turpentine form disks which soon disappear with decomposition, and their carbon blackens the acid.

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54. We do not think it necessary to apologize to the reader for having extended this paper beyond the limits, which a *soap-bubble* would seem to justify. We must remind him that, when any investigations of such a man as Newton have to be considered, the veneration due to so great a philosopher, and the admiration due to those works with which he has enriched posterity, alike prevent a meagre notice, or a hasty abridgment. There is this peculiarity in all the performances of great minds, viz., they admit of minute inspection. It follows, therefore, that an abridgment of such works is only a mutilation, whose apparent simplicity is deceptive; since it too often proceeds from the omission of those details, which constitute the solidity of the results, (and most of Newton's have stood the test of more than a century,) and render them capable of application.

XII.

THE SUN-DIAL.

Section I. Introduction. On the various Divisions of Time.

To ask or search, I blame thee not; for Heaven
Is as the book of God before thee set,
Wherein to read His wondrous works, and learn
His seasons, hours, or days, or months, or years.—Milton.

1. It is a remarkable instance of the limited powers of human language, that *Time*—which forms such an important element in all our proceedings, which is said to fly with the swiftness of an arrow by those whose cheerful, occupied thoughts tend to make life the privilege which it was intended to be; but which may be said to "drag its slow length along," by those whom pain, sickness, trouble, or idleness, has rendered dissatisfied with the present:—it is remarkable, we say, that *Time* has never been successfully defined. We know its value; we know that without it we can do nothing; but we are not conscious of its existence until it has passed. If we take our morning meal, for example, and afterwards take an evening meal, we have no means of knowing that the interval of time between them was either long or short, except by remembering how many actions we performed between the two meals. This is a matter of experience, which has grown up with our growth, and strengthened with our strength; and the value of time becomes appreciated by degrees. Yet we cannot define what *Time* is. The mind has a perfect conception of what is meant, when time is spoken of; but cannot put the conception into the form of words. The idea of *Time* resembles a geometrical definition in this:—that complex truths may be deduced from it, but it cannot itself be resolved into simpler elements.

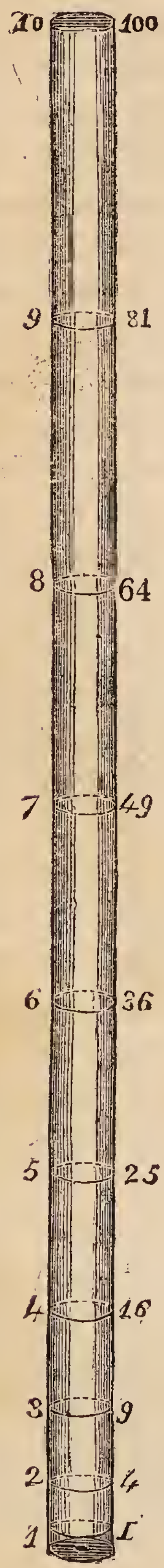
2. Be this, however, as it may, as time is necessarily connected with all our actions,—as the value of human labour is estimated by the quantity of time, during which that labour has been exerted,—as one of the circumstances which distinguish the wise man from the unwise is a due appreciation of the order of events, whether in scientific or social life,—as our knowledge

of wherein consists human life, is built up almost wholly of observations or events, occurring in separate portions of time, from the cradle to the coffin,—as these are some of the important effects, which time produces on the current of human thought and feeling;—it becomes necessary that the means be found of affixing a proper value to the distinct portions of time, as they occur. The relative terms, "long time," and "short time," should have definite values given to them, (according to the circumstances of the case,) by assuming some standard with which they may be compared. This standard should be such as all nations and all ages may acknowledge:—such, that the writers or teachers of one age should be perfectly understood by those of after ages, when speaking of successive portions of time:—such, that in the commercial and social transactions of life, a promise to fulfil a certain agreement at a certain time, should admit of one, and but one, interpretation, as regards the time spoken of:—such, that the astronomer, in noting the periods in which the heavenly bodies perform their secular, annual, or daily motions; or the chemist, in specifying the period in which a process of decomposition or recomposition would occur—might be perfectly and correctly understood by other philosophers, whether in their own country, or in foreign lands, whether of that same age, or of subsequent times.

3. There was an attempt to produce a time-measuring instrument in early ages, by employing a vessel of water, at the lower part of which was an orifice through which the water flowed slowly into a vessel beneath. The laws of liquid equilibrium teach us that the quantity of water which flows out of an orifice at the bottom of a vertical vessel, in any given time, depends on the size of the orifice, and on the height of the column of water above it; and that with any given size of orifice, if the vessel be cylindrical, the quantity which flows out varies as the square of the time which the whole quantity would take in flowing out. If, for example, the orifice were of such a size that 1 inch of depth of water in the vessel would flow out in 1 second; then, if a quantity of water equal to 4 inches in depth, be poured into the vessel, the whole of it would flow out in 2 seconds,—the square of 2 (the number of seconds), being 4 (the number of inches); whereas, if the quantity varied simply as the time, instead of as the *square* of the time, only 2 inches would flow out in 2 seconds. Again: if the cylindrical vessel have a quantity of water poured in equal to 9 inches in height, the whole will flow through the orifice in 3 seconds (the square-root of 9); whereas the simple ratio of

height to time, would have allowed but 3 inches to flow out in 3 seconds. In order to arrive at a clear idea of what is meant by *one quantity varying as the square of another*, we use a figure to illustrate the statements just made.

Fig. 1.



4. Suppose A B, (fig. 1,) be a cylindrical vessel, of any convenient width, (the width having no influence on the ratio above mentioned,) 100 inches in height, and that the bottom B, is stopped, with the exception of a small hole in the middle. On pouring a little water into the vessel, sufficient to fill 1 inch from the bottom, as at 1, we will suppose that quantity to flow through the orifice at the bottom in exactly 1 second of time. Let us now suppose that a quantity of water equal to 2 inches be poured into the vessel: it will be found that less than 2 seconds will elapse during the escape of the water;—although the quantity of water be double of that previously used, the time occupied in its flowing out, will be less than double of that occupied in the former instance, being rather less than 1½ seconds. Let us now pour 3 inches of water into the vessel, and suffer it to flow out, as before: we shall find that this increased quantity will flow out in less than 2 seconds. The quantity is 3 times as much as that at first employed; and yet the time of flowing out is less than twice that which elapsed in the first instance. But, if we increase the quantity to 4 inches, it will be found that the whole will flow out in precisely 2 seconds; that is, 4 times as much water flows out in 2 seconds as previously flowed out in 1 second. This is what is meant by the quantity increasing as the square of the time; 4 (the quantity), being the square of 2 (the time).

The reader can now, by a table of square numbers, determine the quantity which will flow out in any number of seconds. For instance, in our figure, the line marked 1, is supposed to be one inch from the bottom: the line marked 2, then, is 4 inches from the bottom; and the lines marked from 3 to 10 inclusive, are, respectively, 9, 16, 25, 36, 49, 64, 81, and 100 inches from the bottom. The numerals on the left of the figure

represent the series of seconds; and those on the right, the series of inches; by which double series we see the number of inches that flow out in any given number of seconds. Thus, we arrive at the remarkable fact, that 100 times as much water will flow through the orifice in 10 seconds, as flows out in 1 second; and as 100 is the square of 10, the law is put into a scientific form by saying that, *the quantity varies as the square of the time.*

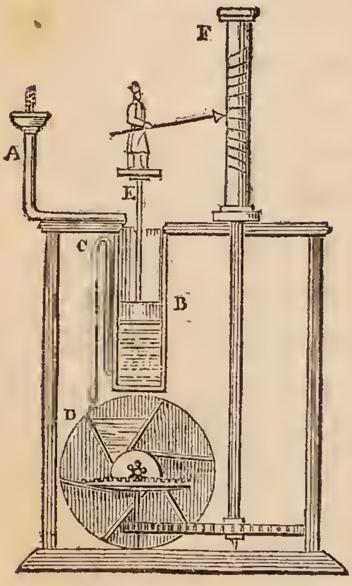
5. This law is important, and is manifested in many different departments of physical science. The cause of this increase of flow through the orifice of the vessel is to be found in the operation of the law of gravitation. A small quantity, say one inch, of water flows through the orifice by virtue of its gravitation towards the earth; but, if there be any water above it, the gravitating force of both portions is accumulated at the bottom of the lower one; which has to bear not only its own weight, but also that of the stratum above it. This accounts for part of the increase; and the remainder is due to the effect of *acceleration*, by which a body moves, not only by virtue of gravitation, but also by virtue of a velocity acquired by previous motion. Thus the topmost inch of water, when it has descended nearly 100 inches, has acquired a velocity, not belonging to it when it first began to descend. This subject has already been treated of in the Hydrometer, par. 21, and note.

6. These being some of the principles which regulate the flowing of water through an orifice, Ctesibius, an Egyptian, who flourished about 130 years B. C., applied those principles to the measurement of time, by filling a vessel to a certain height with water, and making marks on the vessel at distances from the bottom, which were respectively equal to the squares of the series of natural numbers, 1, 2, 3, &c.: he then made the unit of measurement such, that the quantity would flow out in one hour. This is one account: others, however, state that the flowing of water was applied to the measurement of time before his age, but without due regard to the law above mentioned; and, that Ctesibius was the first, who clearly saw the necessity of obedience to that law in any attempt to make this phenomenon a correct measure of the lapse of time. The latter statement, is perhaps, more correct; as we read of the Clepsydra being introduced at Rome, about 159 B. C. By means of this instrument, Julius Cæsar observed that the summer nights in Great Britain were longer than in Italy.

7. The instruments thus constructed were called *Clepsydras*, a word compounded of κλεπτω, *to steal*, and ὑδωρ, *water*, as indicating that the course of time was marked by the

stealthy descent of the *water.* The term *water-clock* has also been applied to them. A great variety of such instruments was constructed by the ancients: some of a most fanciful kind. Many of them by an elaborate combination of machinery marked the hour of the day,—the age of the moon,—the position of the sun in the ecliptic,—sounded a trumpet,—threw stones and other missiles,—imitated thunder and lightning, and performed various other wonders, some of which were undoubtedly true, but others we may be permitted to question.

Fig. 2.



8. The following figure, (fig. 2,) represents a clepsydra, said to have been contrived by Ctesibius, which will serve to show the general construction of the instrument.

The water flowed out from a vessel not shown in the figure through the pipe, A, into the cistern, B, and filled it in one day of twenty-four unequal hours; and when the water, which rose in the leg of the siphon-tube communicating with B, flowed over the curved part, C, this tube quickly emptied the vessel into one division, D, of a water-wheel, which was thus caused to turn round, and to throw out the water, in consequence of the weight; so that the division, D, was thus made to sink down on one side of the axis of the wheel. This wheel was furnished with pinions, and toothed wheels; and being made to perform a part of its revolution, each day, by the falling of the water, it caused the column, F, to rotate on its axis once in a year; or $\frac{1}{365}$th part of one revolution each day. This column had straight lines lengthwise, and curved lines round it, which latter divided the former into twenty-four parts, varying in their distances, as the lengths of the hours varied: so that a new scale of division was every day brought opposite to the dart held in the hand of a figure, placed on the top of a rod, E, which was fixed in a float adapted to the cistern, B.

The first hour of the day was marked by the figure, when the siphon-tube had emptied the chamber, B, and the float had sunk to the bottom. As the water gradually filled this chamber, the figure kept on rising until the float reached C, when the last hour of the day was indicated just before the chamber, B, was again emptied, and the column had turned round $\frac{1}{365}$th part to mark the close of the day.

9. Clepsydras seem to have been common in the early ages, for the purpose of marking the progress of time; which purpose they also served very generally, throughout the dark ages, until about the sixteenth century. In the seventeenth century they were found in France and Italy, made of tin; which countries were the last to use the clepsydra. The imperfections of all such instruments must, however, be obvious. The clepsydras must be supplied with water at certain intervals: the water ought always to be of the same temperature, as heat modifies the degree of facility with which water flows through an orifice: the orifice at the bottom would be likely to enlarge by the friction of the water: and the water would be subject to evaporation, according to the seasons of the year, or even the time of day.

Hollow cups were sometimes used, having a hole in the bottom: these floated upon water, and filling in the lapse of a certain time, sank to the bottom. The burning of a candle, or of portions of a candle, likewise served the purpose of indicating parts of time. This expedient, we are told, was resorted to by Alfred the Great, in the ninth century.

10. The substitution of sand for water, as in the modern hour-glass, seems to have been of comparatively recent origin. But we often find the term κλεψυδρα rendered by *hour-glass.* Thus, Robinson says, in reference to the circumstance, that counsellors and pleaders in ancient times were often compelled by law to confine their speeches within certain limits, "Lest, however, the length of their speeches should weary the patience of the judges, and prevent them from proceeding to other business, they were limited to a certain time, which was measured by *an hour-glass used with water instead of sand;* and, that no fraud or deceit might be practised, a person was appointed to distribute the water equally to both parties. When the water had run out of the glass, they were to conclude their speeches. The speakers were so careful not to lose or mis-spend their water, that whilst the laws quoted by them were read, or if any other business intervened, they stopped the glass. If, however, any person had ended his speech before the time allowed him had expired, he was permitted to give the water that remained in the glass to another speaker."—*Antiquities of Greece.*

11. The hour or sand-glass is liable to the objection, that it requires a horary attendant; as is intimated in the beautiful glee,—

Five times by the taper's light
The hour-glass we have turned to night.

It has almost entirely given way to more useful, because to a greater extent self-acting, instruments; and it is now seldom seen except upon the table of the lecturer, or private teacher; in the study of the philosopher; in the cottage of the peasant; or in the hand of the old emblematic figure of Time, conspicuous in the window of the clockmaker. The half-minute glass is still employed on board ship; and the $2\frac{1}{2}$ or 3-minute glass is also in vogue with the housekeeper or bachelor, who boils an egg with that exactness of time which the little sand-glass ensures.

12. But there are several remarkable circumstances attending the flow of sand through an aperture, which make the hour-glass a better measurer of time than is generally imagined. The flow of the sand from one bulb to another is perfectly equable, whatever may be the quantity of sand above the aperture. The stream flows no faster when the upper bulb is almost full, than when it is almost empty: this we should perhaps scarcely expect; but imagine that, when the upper bulb was full, the pressure of the sand from above would urge the stream more quickly through the aperture at the beginning of the hour than towards its close. That such is not the case the following experiments will show.

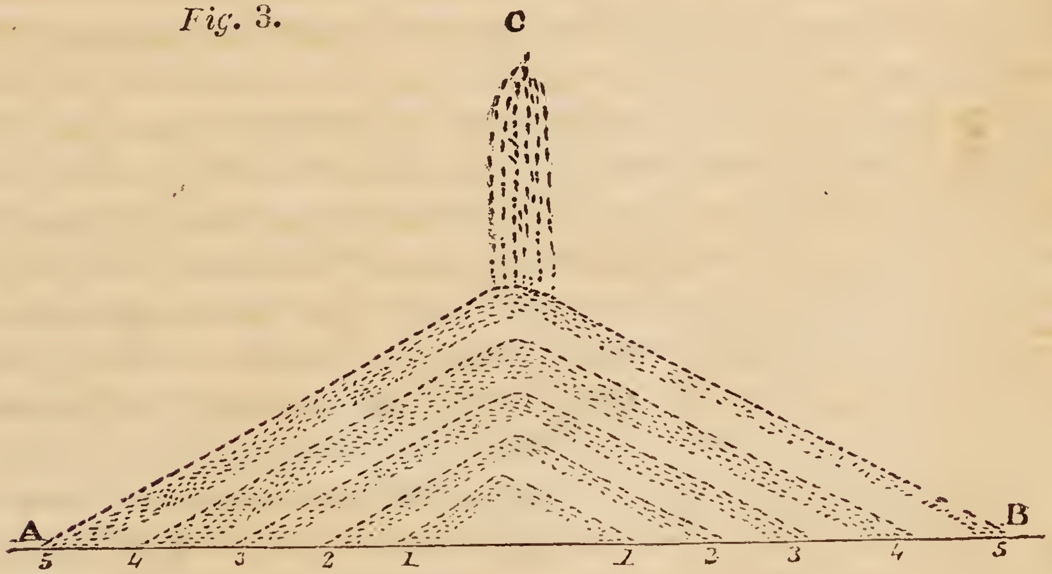
13. Procure a tube of any length and diameter; close one end with a piece of writing-paper, the edges of which may be secured with paste or string to the exterior side of the tube. Make a small hole, about $\frac{1}{8}$th of an inch in diameter, in the centre of the paper bottom; place the finger lightly over this, and then fill up the tube with fine, dry sand. If the tube be suspended, and portions of the sand be allowed to flow out, each portion sufficient to fill a small cup; then, if the time required to fill this cup twice or thrice be noted, the time will in every case be the same. Or the tube may itself be graduated on the outside, after pouring into it equal measures of sand, and making marks on the outside to indicate the height of the sand in the tube after each addition. The times will then be noted that the sand occupies in falling from one division to another; and it will be found that these times are all equal.

When the sand is flowing, we may exert whatever pressure we please upon the upper surface of the sand; and, if we take a cylindrical plug, and force it down upon the upper surface of the sand, we shall not be able in the least to accelerate the descent of the arenulous stream: it will flow on quietly and equably, uninfluenced by our exertions to hasten its progress. This part of the experiment will be found to apply equally well,

if the lower end of the tube be covered only with a piece of moistened silver paper, which shall adhere to the tube only through the influence of the moisture.

14. Now, to explain these remarkable phenomena, we must notice that, when sand is allowed to fall quietly upon a plane surface it will form a conical heap, whose sides form with the base an angle of about 30°. Thus, in the following figure, (fig. 3,) sand falling upon a surface, A B, from C, a source above, forms at first the small cone, (1, 1,) which increases to (2, 2), (3, 3), &c., the sand constantly falling down a conical surface, whose inclination is 30°. This may be observed at every brick-

Fig. 3.



layer's scaffold, when mortar is made: the sand, one of the ingredients of mortar, is sifted through a screen, placed at an angle of about 40° or 50°; and the sand, falling through, forms a conical heap, not quite so regular as that which has passed down through the aperture of the hour-glass; but still its angle will always be about 30°. Even, when dry sand is tossed out of a cart or wheel-barrow, it forms a similar cone.

15. As sand, therefore, falls at a given angle, it is easy to conceive the inclination which it assumes in the tube. The latter is filled by a succession of conical heaps, and the bottom of the tube bears the pressure of the first heap only; and the succeeding heaps are prevented from exerting any *perpendicular* pressure, since they rest merely against the *sides* of the tube: so that, when the pressure is exerted from above, it is transmitted laterally to a small extent, and not perpendicularly.

16. The reason then why the sand flows so equably is, because the lowest heap is not influenced by the pressure of the heaps above. On this principle are formed those pleasing exhi-

bitions of landscapes with moving figures, machinery, &c., the motions of which are produced entirely by the flow of sand.

The regularly accumulating heaps of sand in the lower part of the hour-glass are prettily alluded to by Bloomfield in one of his rural tales:—*The Widow to her Hour-glass.*

> I've often watched thy streaming sand,
> And seen the growing mountain rise,
> And often found life's hopes to stand
> On props as weak in wisdom's eyes:
> Its conic crown
> Still sliding down,
> Again heaped up, then down again;
> The sand above more hollow grew,
> Like days and years still filtering through,
> And mingling joy and pain.

17. The clepsydra and the hour-glass, such as we have described them, are subject to the acknowledged inconvenience of being *empirical;* viz., they could never be made *standards*, by which one nation might judge of the measures of time of another: which can only be done by the aid of the heavenly bodies, by which an unit of time is determined. This brings us nearer to the subject of this introduction, viz., the influence of the motions of the sun, and of the heavenly bodies generally, in affording the means of measuring time.

18. The power of the mind to carry on a train of reasoning independent of the exercise of the perceptive faculties, is a gift possessed by few. We derive nearly all our knowledge from the evidence of the external senses; and happy is he who can make a good use of the knowledge thus obtained,—who can separate the tares of human experience from the wheat, and apply the latter to the purposes for which it was intended, without the baneful influence of the former. We derive, as we have just said, nearly all our knowledge through a medium which connects the world of the mind with the external world; and we find it difficult to view a train of events in any other light than that which the evidence of the senses has furnished to us. If we see a carriage moving along the street, and were to be told that it was not the carriage which moved, but the stones of the street, and that the carriage was stationary, we should positively deny the fact, as being disproved by the testimony of the senses. It is with a similar feeling, that the uneducated man would firmly contend that the sun moves round the earth every day, and that the earth itself is stationary. The two instances which we have put into juxta-position are not too remote to furnish an analogy; for the evidence of our senses tells us that the wheel moves, but

that the stones of the street are stationary;—that the sun moves, and that the earth is at rest. This is the evidence furnished by the external senses, unaccompanied by a process of reflection on the probable causes and collateral phenomena in each case. The man who gives an opinion, without reflecting on the causes of the phenomena which his external senses have communicated to him, would think there was no more absurdity in asserting that the sun moved and the earth stood still, than that the carriage moved and the stones in the street were at rest.

19. We have frequent proof that a process of reasoning has the effect sometimes of confirming, and at other times of disproving, the evidence of the senses. Thus, in our two instances, a consideration of the causes which produce the two phenomena, and of the circumstances connected with them, teaches us that, in the case of the carriage, reason leads to the same conclusion as perception: but, in the case of the heavenly bodies, perception tells us that the sun moves round the earth every twenty-four hours; while a process of reasoning leads to the conclusion that the earth moves once round on her axis in that time, and that the apparent motion of the sun is wholly due to the real motion of the earth. This we now know to be the case; and yet so strongly do visual phenomena impress themselves on the mind, that we constantly accustom ourselves to a style of observation or remark which conveys the idea of a moving sun and a stationary earth. The greatest astronomers, whether of our own country or on the continent,—whether of our own day or of an age preceding us,—always speak of the sun rising, the sun setting, the sun traversing all the signs of the zodiac in a year, &c.; while they are at the same time fully aware, that this motion is wholly a deceptive or imaginary one, occasioned by the real motion of the earth. The object kept in view by astronomical writers in thus apparently yielding to deceptive evidence, is, to bring the truths which they wish to submit to their readers more within the range of common observation; for it fortunately happens that a very large number of phenomena connected with the motions of the heavenly bodies is as satisfactorily explained on the hypothesis of the sun moving round the earth, as on the correct principle, of the earth moving diurnally on her own axis, and annually in her orbit round the sun. When therefore a train of effects is described as likely to follow *sun-rise* or *sun-set*, on a certain day, the appearance of the sun, as if actually rising or setting, aids the comprehension of the phenomena about to occur; but, if the writer were to describe the phenomena as depending upon *earth-rise* or *earth-set*, (which

are really correct terms,) the impossibility of the reader either seeing or feeling that the earth either rises or sets, would perplex him at the outset, and distract him from the observance of the subsequent phenomena.

20. Thus has the practice continued of detailing all the phenomena of the seasons, and of day and night, as if the sun moved round the earth; and, as we shall of necessity employ the same language, we have made these few remarks to obviate the surprise felt at astronomers still continuing to make incorrect assertions, knowing them to be so. But the instances are not rare in science, in which much has been gained by assuming, as a groundwork, data which will not bear the test of analysis, (considered *per se*,) but which elicit a train of very important consequences; it being, however, provided that means be at hand for converting the false data into true, whenever the circumstances of the case render it necessary. The astronomer, for the sake of perspicuity, assumes that the sun moves round the earth, in speaking of the seasons, &c.; but when treating physically of the laws of gravitation, he finds it necessary to reverse the data, and carry on his processes of reasoning with the especial condition that the earth, as being the smaller body, revolves round the sun; or, in strictness, round a point a little removed from the centre of the sun, which point is the centre of gravity of the two bodies. As, therefore, writers on Astronomy frequently use a style of language which is figurative rather than correct, we, in proceeding with our subject, shall do the same, at least, to a certain extent.

21. The vertical position of the sun, with regard to any spot on the earth, being that in which the greatest amount of heat reaches that spot, and the horizontal position being that in which the least heat is afforded, while he is above the horizon; it follows, that if, for a number of days together, the sun be nearer to the zenith, (or the point immediately over head,) than at another period of an equal number of days, the weather will be generally warmer in the former period than in the latter; and all those phenomena, which depend for their perfection on the heat of the sun, will be more decidedly completed in the one case than in the other. Now, if we notice the position of the sun at the middle of the day in the months of May, June, July, and August, we shall perceive that it is much more elevated, or much nearer to the zenith, than in November, December, January, and February; and, as an accompanying and necessary circumstance, the time which elapses between the rising and setting of the sun, is longer in the former case, on account of the greater extent of

the *path* to be travelled over by the sun; called the *diurnal arc.* From both these circumstances, the heat experienced by the portions of the earth in the northern hemisphere, (in which England is situated,) is greater in the former months than in the latter; and thus our seasons of Summer and Winter arise. If now we consider that there must be a medium between the highest and lowest positions of the sun, and that this medium is attained in the progress of the sun both from the highest to the lowest, and from the lowest to the highest points, we shall perceive that there must be two periods, at six months' distance from each other, in which the sun is at the same altitude at the same hour of the day; and that consequently the heat imparted at those two seasons is equal. Hence arise the two seasons of Spring and Autumn, which, so far as the direct heat of the sun is concerned, are similar to each other: the additional heat experienced in Autumn, over that which is felt in Spring, being due to the accumulated heat of the summer months, which has warmed the crust of the earth, and supplied a fund of caloric which is only gradually dissipated.

22. On the 21st of March and the 21st of September, the altitude of the sun, at twelve at noon, is $38\frac{1}{2}°$, in the latitude of London, that being the constant meridian-altitude of the equinoctial; which is only the extension of the plane of the earth's equator to the starry heavens. On the 21st of June the altitude is 62°, and on the 21st of December it is only 15°. The cause of this variation in the sun's altitude, is to be found in the circumstance that the ecliptic, or the path of the earth round the sun, does not coincide with the plane of the equator. The two planes are inclined to each other, at an angle of about $23\frac{1}{2}°$: when, therefore, the earth is in that portion of her orbit which is farthest above the plane of the equator, the sun's meridian-altitude is $23\frac{1}{2}°$ less than when the two planes cut each other; and when the earth is in that part of her orbit farthest below the equator, the meridian-altitude of the sun is $23\frac{1}{2}°$ greater than at the points of intersection. Hence, as the meridian-altitude of the equator is always $38\frac{1}{2}°$, (in the latitude of London,) and as the sun and earth are both in that plane at the time of intersection of the two planes, (that is on the 21st of March and the 21st of September,) it follows that the greatest altitude of the sun is $38\frac{1}{2}° + 23\frac{1}{2}° = 62°$; and the least altitude $38\frac{1}{2}° - 23\frac{1}{2}° = 15°$, as before stated.

23. Now the early nations, such as the Jews, Chaldeans, Egyptians, &c., must have soon observed this succession of seasons: that a hot season was succeeded by a milder season: that that this gave way to another which was colder: that this latter again changed to a milder season: and lastly, that the hot sea-

son came round again. These changes occurred every year in the same order, and it was therefore natural that people should mark the return of similar seasons as a means of estimating the progress of large intervals of time. Hence originated the *year*, a division of time which has been acknowledged and followed by almost every nation upon earth; as the produce of the ground, and consequently, the materials for food, are essentially dependant on the recurrence of certain seasons. It mattered little what point of time was taken as the commencement of the year: provided the succession of hot and cold, wet and dry, be duly regarded, it was of small consequence which season was taken for the commencement of this cycle, or round of changes. Previously to the year 1752, the year, in this country, began on the 25th of March; but at the period just named several alterations took place in the mode of reckoning time: one of which was, the suppression of eleven days between the 2nd and 14th of September, in order to correct the error which had accumulated in a long series of ages, by the civil year having been made somewhat longer than the true solar year. The former had been reckoned at 365 days, 6 hours; while the latter is 365 days, 5 hours, 48 minutes, and 49 seconds. Another alteration consisted in reckoning the beginning of the year from the 1st of January, instead of from the 25th of March. This accounts for the double dates, which we frequently find attached to historical events between the time of the reformation of the Calendar by Pope Gregory, A. D. 1582, and the adoption of this reformation in England. Thus, for instance, the death of King Charles the First is recorded by one historian as taking place January 30th, 1648, and by another 1649: the former using the *old*, and the latter the *new* style. Hence we usually find this date written 1648-9. But to return:—

The succession of four seasons made, as we have seen, a convenient indication of a portion of time, equal to one seventieth part of what has been designated by the inspired writer as the age of man, "three-score years and ten." For sowing, planting, and gathering in the fruits of the earth,—for laying up a store of provisions against seasons of sterility and scarcity,—for entrapping and appropriating as articles of food, the living denizens of the waters,—for hunting the wild or rearing the tame animals which might be subservient for purposes of diet or clothing:—for all these the year, as determined by the succession of seasons, was a convenient, regular, and sufficient division of time. But the necessities of man rendered it imperative that smaller portions of time should obtain a name and an appreciable value.

24. Another mode of division, smaller, therefore, than the

first, was found in the time which elapses between new and full moon. In such a climate as England, where the atmosphere is so humid, so variable, and so liable to throw obstruction in the way of a clear view of the heavenly bodies, the observance of the moon's changes is not attended with such facilities as in a southern climate, or rather, in an equatorial climate; where the zone of the heavens, called the *zodiac,* which contains within it the paths of most of the planets and their satellites, is either vertical, or so nearly so, that, in addition to the greater purity of the atmosphere, the disturbing effect of refraction, or distortion of the rays of light from their rectilinear course, is consequently, as the zenith is attained, almost inappreciable. In the equatorial climates, the phenomena presented by the moon's changes are discriminated in all their gradations; from the hour that a little faint crescent of light appears, as if to usher the young moon into existence, to the time when the fulness of her splendour is manifested, about eleven days afterwards.

> Turned to the sun direct, her spotted disk,
> Where mountains rise, umbrageous dales descend,
> And caverns deep, as optic tube descries,
> A smaller earth, gives us his blaze again,
> Void of its flame, and sheds a softer day.
>
> *   *   *   *   *
>
> Wide the pale deluge floats, and streaming mild
> O'er the sky'd mountain to the shadowy vale,
> While rocks and floods reflect the quivering gleam,
> The whole air whitens with a boundless tide
> Of silver radiance, trembling round the world.

We cannot wonder, if so beautiful an object as the moon has at all times attracted a large share of the attention and observation of the inhabitants of those regions in which her splendour is best appreciated; accordingly, we find that in all rude, uncivilized nations, particularly those of the equinoctial regions, the progress of the moon has been made a measure of time. The ancient Jews distinguished the new moon by a solemn feast, and heralded its appearance by the blowing of trumpets; thereby indicating that a new month had begun; and the phrase "twenty moons" or "thirty moons" frequently occurs in the writings of those travellers, who have mixed with Oriental nations. In our own country we are not so well acquainted with the lapse of time, as indicated by the moon; for we direct our attention to other and more available modes, for the same purpose. We know, however, that the time from full moon to full moon is on an average 29 days $12\frac{3}{4}$ hours; and we might make that an unit of time for those occurrences which would render a year too

long, and a day inconveniently short, for such an unit. There is, indeed, a proof, by the use of another kind of month, that a period about that length is convenient for many of the purposes of life; we allude to the *calendar* month; which is such an arrangement, that the year shall be divided into 12 nearly equal portions, of which 7 consist of 31 days, 4 of 30 days, and 1 of 28 (or 29 days every fourth year). Commercial agreements in the form of bills, salaries and wages paid to soldiers, seamen, and many different classes of operatives and servants—the publication of a large number of periodical works in literature, and many other matters which will occur to the reader—all tend to show that an unit of time between the year and the day is attended with many conveniences.

25. The reason why the age of the moon, or rather the time between new moon and new moon, called a *lunar* month, is not made a standard by us, is, that it would create great inconvenience at the end of the year. The year consists of 365 days (omitting fractions), and we shall find by dividing 365 by $29\frac{1}{2}$ (the number of days, nearly, in what is called the *synodical** lunar month) that we obtain 12 of such months and about 11 days over; so that, if on the first day of the year, the moon happened to be new or full, (for either would do), we should commence two cycles or periods at once, the one a year in length, and the other a month, or moon's age, in length. But we should find on the following new-year's day, that we were nearly in the middle of one of these months;—that is, we should have proceeded 11 days into it, and therefore should be forced to make a separation between those events which we might wish to measure *annually* and those which we should prefer to measure *menstrually*, because the beginning of the year would not, in two successive years, coincide with the beginning of the month. Nay, we should find that 19 years must elapse before the beginning of the year would again coincide with the beginning of the month. For instance, there was a new moon on the 1st of January, 1824,—and the new-year's day will not again fall on the same day with the new moon until the year 1843: hence this period (19 years), is called the moon's *cycle* of changes; because she is, with respect to the days of the year, in the same situation at the beginning

* A *synodical* month is the time from new moon to new moon again, and is so named from the *coming together* of the sun and moon, and consists of 29 days, 12 hours, 44′, 3″:—whereas, the *periodical* month,—the time actually taken up by the moon in its *circuit round* the earth, after allowing for the earth's motion,—is only 27 days, 7 hours, 43′, 5″.

as at the end of that period. As a scientific truth is often more appreciated by reference to a homely illustration, than to one of a more learned kind, we adopt the former. Suppose an agreement for a year were entered into between two persons, by which one was to pay the other a sum of money, or a proportionate part of this sum, if the agreement held good but for a part of the period, and that the parts should be estimated by months. If now the original or synodical month be taken as part of the longer period, both parties would be much perplexed to determine what portion of the whole sum should be reckoned for one or more months: the year must be divided, not into 12, nor into 13 months, but between the two, viz., into $12\frac{2}{5}\frac{2}{9}$ths :—a complexity of which few trading or commercial people are sufficiently fond of mathematics to approve. But by dividing the entire year into 12 parts, and affixing a distinct name to each part, and agreeing that the small difference of length between the several months shall not be considered as disturbing the equity of the arrangement, all the advantages of having an unit of time only $\frac{1}{12}$th as large as the year are realized. In accordance with this arrangement we find that if a bill of acceptance be drawn for 3 months on the 1st of February, it is due on the 4th of May; and if drawn on the 1st of March, it is due on the 4th of June; although the period in the latter case is 95 days, while in the former it is only 92. This difference is overlooked, on account of the conventional facilities, which the division into calendar or civil months is found to afford.

26. It thus appears that, although we do not measure any portions of our time, or regulate the transactions of life in our own country, by the revolution of the moon, yet the *monthly* division, which is found so convenient to us, is evidently borrowed from the apparent time which the moon occupies in going once round the earth; and we are therefore justified in saying that the moon's motion has given us one of our modes of dividing time.

27. However, still smaller portions are necessary to be indicated, for many of the purposes of life; and one, which is nearly as ancient as any of the others, appears to have been derived from the scriptural statement, that the Great Author of the universe, having in six days perfected His labours, rested on the seventh. This seventh day, therefore, being considered as a day of rest, was received by the Jews as a day set apart for devotional purposes; and thus forming a point of distinction between that day and the other six days of the week, gave rise to a period of time, to which the term *week* was applied. We

must here remember that all measures of time must be denoted by the recurrence of similar phenomena, no matter of what kind, provided they be equidistant; and if we were disposed to look for the recurrence of a natural phenomenon indicating the length of a week, we should point to the time of the duration of each of the moon's phases, of which there are four in the space of a lunar month; each of which phases endures for about seven days.

28. In the early ages, when gods and goddesses, shepherds and shepherdesses, warriors, kings, fairies, magicians, and demons, were so strangely mixed up in the details, not only of the poet, but also of the historian, we need not wonder that the heavenly bodies were supposed to exert a great influence on sublunary affairs; and that the warm imaginations of the men of those days gave birth to that deceptive and groundless study which, under the name of *astrology*, and still later, under that of *fortune-telling*,—has turned so many heads, and emptied so many purses. It is not now possible to discover who first applied the names, or determined the influence which the planets were deemed to exercise on the affairs of this earth. But the supposed law of the case was this:—that Saturn, Mars, Jupiter, the Sun, the Moon, Venus, and Mercury, each ruled the destinies of the earth one hour at a time, and was then succeeded in the government by another; until all seven had gone through this routine; after which the same series began again. It was further arranged that each day should be named after the heavenly body which was *in the ascendant*, or on the throne, if we may use the term, on the first hour of that day. Thus:—the day which we now call Saturday, was dedicated to Saturn, because he ruled on the first hour of that day; the six others came in their regular turn; and the eighth hour fell again to Saturn. After going over the series as before, the fifteenth, and then again the twenty-second hour, came under the rule of Saturn,—the twenty-third to Jupiter, and the twenty-fourth to Mars; after which the next hour (which was the first of a new day) came under the rule of the Sun, whose name therefore was applied to that day. In the same way we find that the first, eighth, fifteenth, and twenty-second hours of Sunday came under the rule of the Sun; the twenty-third under Venus; and the twenty-fourth under Mercury; which brought the first hour of the following day under the rule of the Moon:—hence the term Moon's-day, or Monday. Proceeding in a rotation similar to the above, we obtain the series of days thus:—Sun's day, Moon's day, Mars' day, Mercury's day, Jupiter's day, Venus' day, and Saturn's day; which

are respectively, in modern language, Sunday, Monday, Tuesday, Wednesday, Thursday, Friday, and Saturday. The words Tuesday, Wednesday, Thursday, and Friday, are derived from Tuisco, Woden, Thor, and Friga, four of the Saxon deities who were worshipped in this country before the introduction of Christianity.

29. Thus sprang up the mode of dividing time into weeks, each consisting of seven days; and experience demonstrates the convenience of this division. The publisher of a periodical work may deem a month too large an interval of time between the publication of two consecutive numbers of his periodical; while a daily publication would be inconveniently frequent. A mean, favourable both to the seller and to the purchaser, is found by a weekly issue of numbers. Again:—the wages of labour, if paid monthly to the poorer classes of artificers, would be productive of the evil always attendant on the possession of a considerable sum of money at one and the same time by those of improvident habits. There is, besides, this convenience attending *weekly* payments of salary, viz., that an agreement for a week's services may be offered and accepted, the payment of the salary being weekly; which services being *weekly* are more available in circumstances where a *month's* services may not be required. This may be illustrated by the different modes in which artificers, labourers, and domestic servants, are hired. But the convenience just alluded to, which attends the employment of shorter measures of time than a month in the agreements of masters and workmen, might produce an opposite inconvenience, if the measure of agreement were one *day* instead of one week. These are familiar instances, to illustrate common truths, which the student must not despise, for the great aim of science is to make social life more cheering and valuable to all; and nothing is too humble for our notice, if it tend to the improvement, or convenience, of society.

30. We now pass on to that mode of dividing time which is the most obvious, the most ancient, and the most important, of all: viz., the division into *days*. From the moment that the sun first shed his beams upon the earth commenced this mode of dividing time. The first created of human beings could not have been many hours in existence without observing that the sun rose as if from the distant parts of the earth in the east, in the morning: that he gradually increased his height above the ground: attained his greatest altitude and greatest heating power: declined again towards the earth, not eastward as he rose, but westward: and finally sank, as if into the bowels of

the earth. This splendid vision returned after the lapse of a short period, and the same series of changes occurred: the red beams of the rising and setting sun (made red by the absorbent power of the thick stratum of atmosphere through which they penetrate horizontally):—the brilliancy of the "lofty lord of the heavenly host" at noon-day:—all the changes from one position to another, occurred again in regular order, and after short intermissions. It was impossible for this train of phenomena to occur without impressing on the minds of all, such marked distinctions between the several portions of time. While the sun was above the horizon, all nature was gay: the human being and the other animals, all filled with the gush of life, performed the tasks allotted to them, built their habitations, procured and stored up food, and viewed with admiration the beautiful world around them. But, as the sun finished his daily course, as he dipped beneath the horizon, all nature seemed fitted for repose. The flowers, as if deprived of the spirit which formed their existence, closed their bosoms: the human being, fatigued with his labours, sought his pillow, and forgot in sleep the interval before the next appearance of the sun; and the stilly calmness of all around seemed to mark it as the general slumber of animated nature—

> Now came still evening on, and twilight gray
> Had in her sober livery all things clad;
> Silence accompanied; for beast and bird
> They to their grassy couch, these to their nests
> Were slunk.

31. Thus arose a marked and distinct measure of time: the rising of the sun being the signal that a new day was beginning, and its setting equally implying that a period of rest was approaching. Need we wonder therefore that the *day*, or the period between sunrise and sunset, became an universal measure of time among all nations? We must here speak of an inconvenience, felt by all in entering into detail on this subject. We mean the employment of the term *day*, to indicate the time that the sun is *above* the horizon; as also the time from sunrise to sunrise, or from sunset to sunset, which includes both *day and night*. This inconvenience has sometimes been avoided by the adoption of a term, containing within itself the meaning which ought to be attached to it: it is the word *Nycthemeron*, from a compound Greek term νυχθημερον, *night-day*, which implies both *day* and *night*. In like manner, whenever any doubt as to our meaning may arise, we shall employ the term *full day* to designate the whole period of twenty-four hours.

Soon after time was distinguished into days, it was usual for many people to estimate the lapse of it by *nights*. Not only do we learn this from ancient authors; but we observe it among some of the central nations of Africa at the present day. This practice probably existed once in this island; as we may judge from the surviving words, "se'nnight," "fortnight," the former being *one week*, or *seven nights*, the latter *two weeks*, or *fourteen nights*.

32. The full day then was a most available period as a standard unit of time, and as such is universally appreciated all over the world. But still this was not sufficient for all purposes. The religious systems of different sects had ordained that certain religious offices should be performed three or four times in the course of one full day; and it became necessary to obtain the means of fixing those periods. A very early division was into four parts, the boundaries of which were marked by phenomena of a distinct and definite character. These distinctive phenomena were, 1st, When the sun lifts his head above the horizon; 2nd, When he attains his greatest altitude; 3rd, His sinking beneath the horizon; and lastly, The period of his greatest depression below the horizon. These points of time, under the names of sunrise, noon, sunset, and midnight, were frequently ordained as the hours for prayer,—for relieving the watch,—and for performing other offices arising out of the civil or religious regulations of the people.

33. In the course of time a further subdivision arose, from a wish that the day between sunrise and sunset should be divided into four parts instead of two; and that the night likewise should be thus equally divided. Accordingly, we find that the Jews had their morning and afternoon hours of prayer, the former at the third hour of the day, or 9 o'clock A. M., and the latter at the ninth hour, or 3 o'clock P. M. The night was divided by the Romans into four *vigiliæ*, or watches, which were distinguished by the terms *even*, *midnight*, *cock-crowing*, and *morning*. These divisions, however, were attended with this inconvenience; that the same two boundary-points did not always include between them equal intervals of time: that is, for instance, at one period of the year, the time from noon to sunset was longer than at another period of the year. This difference of length did not arise from any variation in the time of noon, but in that of sunset, and was occasioned by the obliquity of the equator to the ecliptic. If those two planes coincided, or (what is equivalent,) if the sun were at all times vertical to some part of the equinoctial line, the day would

always be exactly as long as the night all over the earth. As the conditions are, however, respecting the *positions* of those two planes, there are but two days in the year when the sun is vertical to the equator, on which two days the sun is perpendicular at the points where the planes of the equator and the ecliptic cut each other. According to our mode of dividing the months, this occurs on the 21st of March and the 21st of September. On those two days, therefore, day and night are precisely equal in length, not only at all places on the equator, but at every part of the earth's surface. When each of those two days, however, has passed by, the sun deviates from his vertical position at the equator, and acquires what is termed *north* or *south declination*,—north from March towards Midsummer, and south from September towards Christmas.

34. Now, one consequence of the particular central situation of the equator, as respects the revolution of the earth on its axis, is, that the day is there equal to the night at all times, whether the sun is vertical to the equator or not; because the equator always cuts the horizon into two equal parts, and must always, in half its extent, and no more, be enlightened by the sun, so long as the sun's declination is less than 90°. With other parts of the earth, however, the case is different; for, in these instances, the ecliptic, in which lie the rising and setting points of the sun, never cuts the horizon into two equal parts except on those two days in the year, when the ecliptic and equator coincide, viz., the vernal and autumnal equinoxes. On all other days the segments of the horizon are either greater or smaller. The greater segment lies northward in our winter, and the smaller in our summer; and *vice versâ*. Again, on the other hand, all the parallels of latitude are unequally divided by the horizon, except at the equinoxes; the greater segments of these parallels lie northward in our summer, and the smaller in our winter; and *vice versâ*. Thus is determined the condition that the night is longer than the day in winter, and shorter in summer.

35. From these circumstances it followed, that at any place not situated on the equator, in which the day was divided into twelve hours, and the night likewise into twelve, the day-hours were longer in summer and shorter in winter than the night-hours, because the gradual increase in the length of day-light in the former season, necessarily lengthened the interval between sunrise and sunset, and diminished the interval between sunset and sunrise; and *vice versâ* in winter. The peculiar circumstances of the case, therefore, prevented this from applying

universally as a standard of time. Suppose, for instance, that certain civil or military offices had been ordered to be performed at all parts of the Roman Empire during the interval between noon and sunset. This order would have had a different effect, and would have pressed unequally at provinces situated at different latitudes with respect to each other. If Britain and Carthage had been two of the provinces in question, and the 24th of June the time of the event, the period, although on the same day, and going by the same name, would have a different length at each of the two places; viz., about $8\frac{1}{4}$ hours in Britain, and about 7 hours in Carthage: that is, the sun would set on that day at about a quarter past 8 in Britain, and about 7 o'clock at Carthage. This, it is true, is but a suppositive case; but it will be sufficient to show the inconvenience which may arise from employing a *variable* standard. We can all conceive what would be the embarrassing effect, if the yard or the gallon were subject to fluctuations in dimensions; this will assist us in appreciating the superiority of a constant over a variable standard of time.

36. We thus bring down our division of time into hours, a term which has had different values under different circumstances. The first horary division of the full-day was into 12 parts, 6 of which belonged to the day, and 6 to the night; and, therefore, shared with the *vigils*, or *watches*, the inconvenience of being variable in length, according to the hour of sunrise or sunset. It does not appear, from the testimony which has been handed down to us, that this mode of division was either spread among many nations, or of long continuance where it was first adopted. We find that a division into 24 parts, or hours, was soon employed, to the exclusion of the former mode, nor does it appear that the *duodecimal* arrangement has ever again been employed since the invention of the more modern method.

37. It is curious to observe the difference which has existed among nations regarding the decision of the question,—"What shall be reckoned as the beginning of the day?" The Jews, the ancient Greeks, the Chinese, and other nations, formerly did, and some of the modern European nations still do, reckon the hours from sunset to sunset: but with this difference, that some of the ancients reckoned the night to consist of 12 hours, and the day of 12 hours, whether the sun rose early and set late, or rose late and set early; while the moderns, in most cases, reckon all hours equal to each other. Again, the Babylonians, the Assyrians, the Persians, and Eastern nations generally, (as well

as a few in more modern times,) reckoned the beginning of the day, as well as of the *full-day*, at sunrise, the hour of sunrise being the first hour. A third mode of reckoning was adopted by the Egyptians and the ancient Romans; which was to call the hour of midnight the commencement of the full-day. This plan is followed by ourselves, and by most of the nations of Europe at the present day. We are not aware that the hour of noon has been employed as the first hour of the full-day, except in astronomical computations, and among navigators when out at sea; in both of which cases it is found convenient to consider the point of time when the sun is on the meridian as the termination of one full-day, and the commencement of another.

38. But another point of difference here presents itself to our notice. We are, from habit, so accustomed to a division of the 24 hours into two parcels, in which a series of 12 is repeated, that we are scarcely aware that a different arrangement has at times been used. The first nation which adopted a division into 24 hours, reckoned them on continuously in one series from 1 to 24; so that each part of the full-day had a particular number belonging to it. With us, however, it is not so; 12 o'clock in the day is a symbol of busy active life, when the merchant,—the artificer,—the school-boy, are full of activity and vigour. But 12 o'clock is also a symbol of the hour of rest; when all are either asleep, or preparing for sleep, or entailing upon themselves punishment and future disease by infringing the organic laws of nature. If we were now about to learn the names applied to the hours of our day, we should perhaps find this two-fold meaning productive of complexity to us; but constant habit has removed all confusion in our ideas on the subject. The modern set of astronomical hours resemble the horary division of some of the early nations; for the hours are numbered from 1 to 24. To know, therefore, what is meant by the 19th hour of the 7th of May, for instance, as reckoned *astronomically*, we must remember that the civil or common day commences 12 hours *before* the astronomical day; therefore, the 19th hour of the 7th of May is equivalent to 7 o'clock in the morning of the 8th of May, *civil* time.

39. We thus perceive how much the conventional arrangements of different countries vary, when there is no obvious or powerful reason why they should be alike. In the case of the full-day all nations agree: the event of the first appearance of the sun above the horizon, is so sublime, that all nations are constrained to mark the lapse of time between two such events. But, when they come to subdivide this lapse of time into hours, we find them

differing one from another in four points of view: 1st, The absolute number of hours has in some cases been 12, and in others 24: 2nd, The actual length of the hours has varied (according to the hour of sunset) with some nations, while others have had the lengths of all the hours equal: 3rd, Some have begun the numeral designation of their hours at sunrise, others at noon, a third party at sunset, and the remainder at midnight: 4th, In those instances in which a division into 24 hours has been adopted, the whole 24 hours have been carried on in one series from 1 to 24 by the larger portion of those who have employed this method; while the remainder have reckoned a double series, of 12 hours each, by which there are two hours of each designation, so far as the numeral is concerned.

40. Thus the year, the month, the week, the day, and the hour, have all been chosen by mankind as fitting measures of the progress of time. For events in which the growth, the prosperity, and the decay of nations,—the progress of man from infancy to the grave,—the orbital revolutions of the heavenly bodies, &c., are concerned, a year is the unit of time by which the accumulation of ages is measured. Then we have seen that for many of the manufacturing and commercial relations between man and man, a month or a week has been found more fitting as an unit of time than the period of a year. Then again, for the economy of a domestic circle, and for many of the social duties which bind men into one community, the diurnal and the horary divisions of time have been found productive of much convenience. The many changes and variations of the latter mode of division, without however doing away with it, sufficiently indicate that there is in it a principle of utility.

41. But we do not end here. Useful as the horary division confessedly is, there are many processes, both in the mechanism of society and in the study of science, in which a smaller unit of time is indispensable. Many of the most delicate processes in manufactures would be entirely unsuccessful, unless a 20th, a 50th, or even a 100th part of an hour could be measured; and the minute-gun, the minute-glass, the minute-hand of a clock, &c., are all so many instances that society has found it convenient to have a much smaller unit of time than an hour. The unit employed in most parts of the world is the *sexagesimal;* that is, the 60th part of an hour. It is not easy at the present day to say why 60 should have been chosen as the numbers of parts, into which an hour should be divided. There is nothing in our principle of notation, which renders

such a division more convenient than others; and indeed, the notation employed among most nations is such as to render a different division of the hour desirable. This subject may be illustrated by reference to the division of the circle. The usual mode of dividing a circle is into 6 times 60, or 360 degrees; and each degree into 60 minutes. The number 360 has a greater number of divisors, whereby no remainder is left, than most other numbers of a similar capacity. This consideration, perhaps, originally furnished some reason for the adoption of this number. So much was the inconvenience of this mode of division felt, however, when considered with regard to the decimal notation employed in arithmetical processes, that it was attempted, soon after the invention of logarithms, to construct a table of sines, tangents, &c., in which the quadrant should be conceived to be divided into 100 degrees, and each degree into 100 minutes; by which means any number of degrees and minutes could be expressed under one symbol; whereas, we have now to employ two symbols, or signs, for this purpose, viz., ($^\circ$) and ($'$). For instance, if we had to express the angle 45 degrees 15 minutes, according to the sexagesimal system, we should write it $45^\circ\ 15'$. But to express the same angle by the decimal system it would be 50·25, the four figures all belonging to one denomination, and therefore affording great facilities for practical computation. But, just before the period alluded to above, a large table of sines, tangents, &c., had been constructed on the *sexagesimal* system; and the great labour bestowed on its production rendered mathematicians unwilling to throw away an advantage directly available, for one that was merely prospective. This circumstance determined the perpetuity of the sexagesimal system; and so bound up is that system with all the modern modes of education, that when, at the time of the French Revolution, some of the great mathematicians of that country endeavoured to bring the decimal system into use in weights and measures of nearly all kinds, although they succeeded in their object as far as regarded measures of capacity and of length, they failed in doing so with the graduation of the circle. The centesimal division of the quadrant of a circle was used for some time by the scientific men of France, but it never firmly took root, and is now, we believe, getting out of use. In a word, an improvement of this sort has little chance of being effected, when the method sought to be improved has become part of our mental stock in trade, and has run through all our school-books, from Walkingame's *Tutor* to the *Differential Calculus*. The like difficulty would attend any attempt

to establish the decimal, or centesimal, division of the hour; although, for purposes of computation, the decimal system would be decidedly preferable to the sexagesimal.

42. Some of the most important discoveries in Physical Science have depended on the observation of the accelerative velocities of moving bodies falling to the earth; that is, that bodies move faster when they have been falling for some time, than when they first begin their motion. To ascertain the law of this acceleration, it became necessary to assume a very small unit of time, in order to compare the increments of velocity at different stages of the motion. For this purpose, and others of a similar nature, the *second* has been employed, which is the 60th part of a minute, or the 3600th part of an hour. Had Newton employed a *minute*, as the smallest unit of time, the discovery of gravitation would have had great obstacles thrown in its way, independent of those which naturally belong to so vast a subject. The *isochronism* of the pendulum, that is, its motion in *equal times*, a discovery replete with important consequences, would be embarrassed with perplexing computations, if we had no unit of time smaller than a minute. Every astronomer in Europe now knows, that when he hears the length of a pendulum spoken of as being 39·1393 English inches, it means a pendulum which vibrates once in each second, in the latitude of London (VERNIER, 5); and each of these seconds he knows to be $\frac{1}{3600}$th part of an hour. Thus an uniformity is established, and the value of that small fraction of a minute is appreciated by all.

There have been divisions of the seconds into *thirds*, each of which is equal to $\frac{1}{60}$th of a second; but such a small unit of time, although manageable in an arithmetical process, and appreciable by delicate astronomical apparatus, is beyond the reach of common practical application.

43. We have thus rapidly reviewed the different measures of time from a year to a second, which is the $\frac{1}{31556928}$th part of a year. We may compare the utility which these divisions of time present to us in the affairs of life, to that which results from employing coins of different denominations, from a farthing to a sovereign. A person, who wished to pay a sum of three or four pence to a retail dealer, would find both himself and his creditor much incommoded if there were no coins of less value than a crown or half-crown; while, on the other hand, the merchant, who had to pay a thousand pounds to his broker, would not think the arrangements of the mint judicious, if he were compelled to pay the whole in farthings. So it is with *time:* if one philosopher were to ask another, what is the relation between

the length of a pendulum and the number of its vibrations, and he were to receive a reply that a pendulum 39·1393 inches in length would vibrate 31,556,928 times in a year, the statement would be perfectly correct, but without any practical value, on account of the unit of time being so large. On the other hand, if he were to ask what age was Newton when he made his great discovery of *gravitation*, and were to receive for answer, that Newton was about 757 millions of seconds old at that time, the information, although true, would give very little satisfaction to the querist, on account of the smallness of the unit of time employed. If the answer had been 24 years, it would at once be appreciated; because the unit of time would be more in accordance with the nature of the question.

44. We have now gone over in such a manner as our limits permit, the principal arrangements which men have adopted as units of measurement in any transactions in which time is concerned. This we have done before detailing the mode of determining the *hour* by the sun-dial; because there are different modes of ascertaining with moderate correctness, the recurrence of most of the larger periods of time. We know that, when darkness has succeeded daylight seven times, a week has elapsed; and the memory will tell what portion of that period has at any time gone by. The different phases of the moon, sometimes round, sometimes semicircular, sometimes gibbous, and at other times crescent-formed, afford us a tolerable index of the progress of the moon's age. But the means of determining the hour of the day, are not so independent of instrumental aid.

45. Another reason why we have given the details which have hitherto occupied us is, that many persons, otherwise intelligent, believe that there is something in the nature of things which fixes our standards of time, without any exercise of will or opinion on our parts: that a month is a month, not because we choose to make it so, but because there is something inherent in the nature of time, by which such divisions are ordained. It appears, however, that the assumption of units of time is, for the most part, conventional: that, if we determined that a day should consist of ten hours, that a year should consist of ten months, &c., it might very well be so; and that the change would be in some instances productive of advantage, and in others, of disadvantage. But, although we might have taken any units we please, yet the return of similar seasons of the year, of similar phases of the moon, of successive sabbaths, and of successive periods of rest from daily labour, is so notable, that mankind has been led to adopt these events as marks whereby to separate

time into portions, more or less large, and which could not be mistaken.

We proceed now to the consideration of the principles on which the *Sun-dial* is constructed; and to the application of that instrument for the purpose of measuring off successive hours.

Section II. On the Nature and Construction of Sun-dials.

Non numero horas nisi serenas.

So passes, silent o'er the dead, thy shade,
  Brief Time! and hour by hour, and day by day,
The pleasing pictures of the present fade,
  And like a summer-vapour steal away.

And have not they, who here forgotten lie,
  (Say, hoary chronicler of ages past,)
Once mark'd thy shadow with delighted eye,
  Nor thought it fled,—how certain and how fast?

Since thou hast stood, and thus thy vigil kept,
  Noting each hour, o'er mould'ring stones beneath,
The Pastor and his flock alike have slept,
  And "dust to dust" proclaim'd the stride of death.

Bowles's *Sun-dial in the Churchyard.*

46. If those who live northward of the tropic of Cancer, such as the inhabitants of Europe, &c., look at the sun at twelve at noon, their faces are towards the south, whatever be the period of the year, or the latitude of the place. The sun, therefore, attains his meridian exactly at the south of us. Let us now consider towards what quarter of the heavens we must direct our attention, in order to see the sun rise. We shall find that that point will be precisely east of us on the 21st of March, and on the 21st of September, (the vernal and autumnal equinoxes); but that, on all the summer days, the sun has a northern amplitude, or rises to the north of the eastern point of the horizon; and that, during the whole of the winter months, he will rise to the southward of the same point. Let us now turn our attention to the setting of the sun. This occurrence takes place due west of us at the equinoxes. The sun has a northern amplitude; that is, he sets to the north of the west, during the summer months: and he has a southern amplitude during winter. The greatest amplitude, or the greatest distance of the rising sun from the east, and of the setting sun from the west, being, in the latitude of London, about $39\frac{3}{4}°$. If we further observe the position of the sun at noon-day, we find that his altitude is greater at some periods of the year than at others,—

the highest being in summer, as was explained in the former section (22). But besides this, we shall perceive that his greatest altitude above the horizon, on any given day, is exactly at that point of time when he is directly to the *south* of us.

47. From these observations we may draw several conclusions: 1st, During summer, the sun is at any given hour between rising and setting, higher in the heavens, or at a greater altitude above the horizon, than at the same hour on the days of the equinoxes; 2nd, That at any given hour on either of the last mentioned days, he is at a greater altitude than at the same hour on any of the winter days; 3d, That he describes a larger arc in the heavens on a summer's day than on the day of the equinox, and larger on the latter than on a winter's day. We shall further perceive that he rises exactly at 6 o'clock in the morning at the days of the equinoxes, and sets exactly at 6 in the evening;—that at all times when he rises southward of east, the hour of sunrise is after 6 in the morning; and of sunset, before 6 in the evening;—but that, if he rise northward of east, the hour of sunrise will be before 6 in the morning; and that of sunset, after 6 in the evening. It would not be correct to say that either one of these phenomena is the *cause* of the others; as they all depend on other circumstances, the principal of which is the obliquity of the ecliptic to the equator. The northern amplitude, the early rising, the larger diurnal arc, and the greater altitude, are all collateral effects of the same train of causes; as are likewise the southern amplitude, the lateness of sunrise, the smaller solar arc, and the smaller altitude.

48. Let us now inquire what effect these phenomena will produce on an opaque body, on which the sun is shining. We see a shadow cast behind the body, and observe that this law invariably maintains; viz., that the sun, the opaque body, and the shadow, are all in the same right line. We further perceive that this shadow is not constant in its dimensions. When we walk out at mid-day, in summer, our shadow is three or four feet in length; but if we are in an open plain near the time of sunrise or sunset, we find our shadow extends to a great distance, and exhibits proportions more remarkable for length than breadth. At any intervening hour of the day, the length of the shadow is between these two extremes. Now, if we could find that the variation in the length of the shadow followed any regular law according to the time of day, we might avail ourselves of that law for the purposes of measuring time:—as Aristophanes, the comic poet of Athens, who wrote about 430 years B. C., makes one of his characters say,—"But you will take due care to go to

the feast, when the gnomon's shadow is ten feet long." The Moors of Africa were also once in the habit of estimating the time of the day by the length of their shadows, which they measured with their feet; the shortest shadow indicating noon. The extremes, however, in these instances are so great, that they must obviously occasion great perplexity. If, for example, we found that a stick, four feet high, casts a shadow three feet long at noon, and four feet long at 2 o'clock, we might determine those two hours, and perhaps some neighbouring periods, without much difficulty; but when we find that, as sunset approaches, the shadow lengthens to ten, twenty, or thirty feet, the task of measuring overbalances the advantage of the knowledge gained. We must therefore endeavour to make the shadow available in some other way.

49. Suppose now that the *direction* of the shadow is made the object of comparison, instead of its length. We shall see that at twelve at noon the shadow is projected due north; that at sunrise it is nearly, but seldom quite, due west; and that at sunset it is eastward. We shall likewise see that the path of the shadow travels round, in the portion of time between sunrise and sunset, from west by north to east; that is, just in the contrary direction to the motion of the sun, or in accordance rather with the diurnal motion of the earth.

50. We will now assume that the observer, in order to make the motion of that shadow a measure of time, selects a period when the sun is above the horizon exactly half of a full-day; or, which is the same thing, when the day and night are equal. We will suppose him to have a pendulum, vibrating seconds, which he knows, therefore, will make 43,200 vibrations from sunrise to sunset; one twelfth part of which, therefore, or 3600, is the number of vibrations which will be made in each hour. He marks the direction of the shadow on the ground, at the expiration of each series of 3600 vibrations, and those marks he may consider as the symbols of the progress of time. To test the accuracy of his proceedings, he watches the direction of the sun's shadow, at precisely the same hours of the day in the middle of summer and the middle of winter. But he finds that the marks he formerly made are no longer correct indicators, the 12 o'clock shadow alone excepted. The 3 o'clock line in summer will no longer be the 3 o'clock line of spring and autumn, and still less will it be the 3 o'clock line of winter. The winter hour-lines will be congregated nearer together; while the summer hour-lines will be separated by wider intervals, than those of winter, or of spring and autumn.

51. He would, therefore, find that his endeavour to obtain a correct measure of time by permanent marks would be frustrated; and he may then ask, "Is there no mode of arranging the conditions of the problem, by which the same hour-lines will give equally correct indications at all seasons of the year?" We will now show that this question may be answered in the affirmative, and the inquiry into the cause of the failure of the former experiment will be instructive.

The cause of that failure was, that the stick was supposed to be placed *vertically* in the ground, without inclination in any direction. Let us, then, suppose that, in order to obviate this objection, he inclines the stick towards the *east*. He will then find that the hour-lines on the ground, as determined by the shadow, deviate in a small degree, at different seasons, for those hours when the sun is near the east or the west, but considerably at the hour of noon. On reversing the inclination, and making it *westward*, the results are nearly the same as when the inclination was east. Let the inclination be now towards the south; and it will be found that the noon-lines coincide in direction at all seasons, but that the morning and afternoon hour-lines differ greatly at different seasons. It thus appears that neither the vertical position, nor an inclination towards the east, the west, or the south, will produce the desired effect of making any given hour-line at midsummer coincide in direction with the same hour-line at spring, at autumn, and at winter.

52. We will now suppose that the stick is inclined towards the north. Here it will be perceived that these discrepancies are gradually diminished, and that a point may be attained, at which any given shadow-line will always be such, without reference to seasons. Thus the desired object has been attained; that is, a mode of fixing the stick has been found such, that its shadow will be cast in the same direction, at the same hour, on every day in the year. It becomes desirable, therefore, to note what that favourable position is; and we find that it is, in every case, such a position that the angle which the stick forms with the horizon, or the ground, shall be equal to the latitude of the place in which the observation is made. In the latitude of London, which is $51\frac{1}{2}°$ north, the stick is to be inclined towards the north at an angle of $51\frac{1}{2}°$ with the horizon; or, which amounts to the same thing, an angle of $38\frac{1}{2}°$ with the perpendicular.

53. In this way we elicit a general law, to the effect, that, if the stick be inclined at an angle with the ground equal to the latitude, (the inclination being north or south, according as the

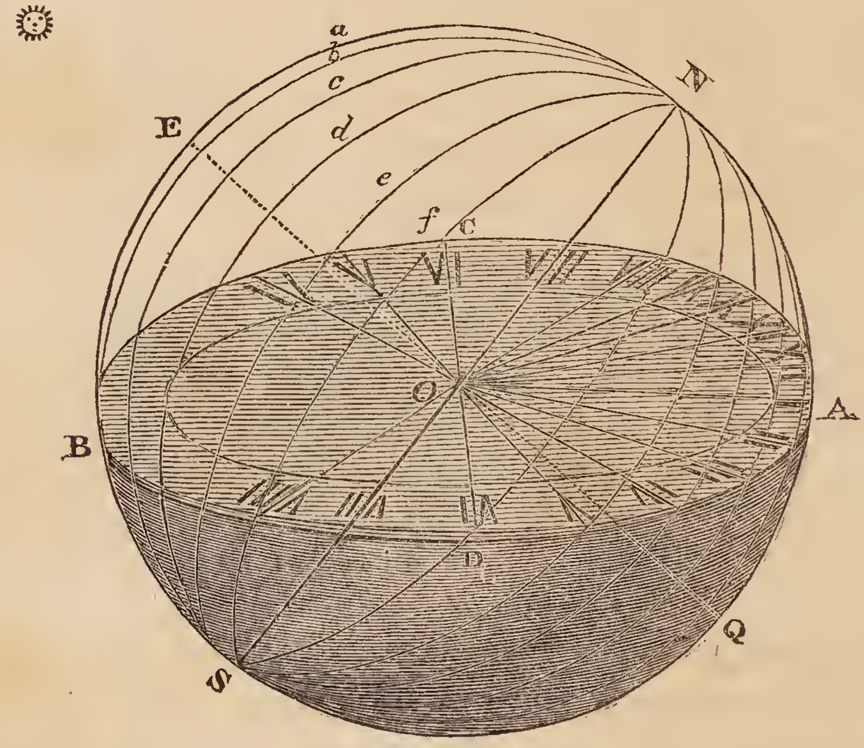
latitude is north or south), then will the direction of the shadow of the stick, at any hour, be a correct type of that hour, and available at all seasons. Thus have we constructed what is neither more nor less than a *sun-dial;* which is merely a contrivance for marking the course of time, and indicating the termination of successive hours by the shadow of an object placed on purpose to cast such shadow. It is important always to know wherein consists the *principle* of an instrument, as distinguished from those particulars which are merely productive of greater niceties, after the principle has been once attained. Thus, the principle in the present case is, that the stick should be in the plane of the meridian; that is, not inclined either to the east or west, but towards the pole which gives the name of north or south to the hemisphere, in which the observation is made. The minor, but at the same time, necessary adjuncts, are, 1st, Such a form of the stick as will permanently retain its position; 2d, A perfectly horizontal surface on which to mark the lines; and 3rd, An accurate determination of the north and south points of the horizon.

54. We have now to consider what is the reason that the accuracy of indication spoken of above, is attained by one definite position of the stick. It will be easily understood that, if a person were standing on the surface of the earth at the equator, the axis of the earth would be parallel with the horizon; but that, if he were standing at either pole, the axis would be directly perpendicular or vertical. Now, as there is of course, 90° of difference of position between a horizontal and a vertical line, and 90° likewise between the equator and the pole, it follows that, at any intermediate point on the earth's surface, the axis forms an angle accordingly. It is found, then, that at any place on the globe, the deviation of the axis of the earth from the vertical position is equal to the polar distance of the place; and that its deviation from a horizontal direction is equal to the latitude of the place,—these being merely two expressions for the same law. At the latitude of $51\frac{1}{2}°$, therefore, or where the polar distance is $38\frac{1}{2}°$, the axis declines $51\frac{1}{2}°$ from the horizontal position, which is $38\frac{1}{2}°$ from the vertical. By the term *polar distance*, we mean the arc comprehended between the zenith of the place and the axis of the earth infinitely prolonged northward, or southward, according as the place is north or south of the equator.

55. It thus appears, that the axis of the earth is inclined at the same angle as, and is therefore parallel to, the stick which casts the shadow in the previous experiment. Now, we must

endeavour to show how the axis of the earth is concerned in the determination of the shadows. Let N A S B, (fig. 4), represent the earth; but with the supposition that it is transparent, so as to show a solid axis N S, passing through it. We will further suppose that there are twenty-four semicircular wires *a b c d*, &c., encompassing this sphere, and meeting at the two poles; and that the sun is at a great distance off in the direction ☼, in one point of his daily path. Then, if the sun revolve round the sphere in the plane ☼ E Q, we shall observe the following phenomena. As any one of the meridians, or semicircular wires, all of which are equidistant, comes between the sun and the axis of the sphere, the meridian will shade the axis, and the latter will

Fig. 4.



shade the remote meridian, directly opposite to the first. These momentary occultations, for of course they are but momentary, occur at precisely equidistant periods; for the meridians are supposed to be equidistant, and the sun's motion round the globe to be uniform. This we will suppose to have occurred at the vernal or autumnal equinox, when the sun is in the plane of the equator E Q. But now suppose the time to be midsummer; when the sun is vertical at a point $23\frac{1}{2}°$ N. of the equator. Then, in the course of his passage round the earth, with that northern declination, the very same series of occultations will occur as those just described; that is, at twenty-four different periods in the course of the circuit, two meridians, the axis, and the sun, will all be in the same plane: but, *if the axis be misplaced*, the occultations of the axis and of the remote meridian

will not occur at the same instant in every part of the circuit, but will deviate from coincidence, according to the displacement of the axis. Now, this was precisely the case with the hour-lines furnished by the shadow-producing stick. When the stick was parallel with the axis of the earth, the shadow-line at any hour of any day coincided with the shadow-line at the same hour of any other day: and, in the case of the transparent globe,—when the axis was in its proper position, the axis and the remote meridian were occulted by the anterior meridian at the same moment; or, all three coincided in direction, whatever might be the position of the sun. When the stick was vertical, or otherwise deviated from parallelism to the earth's axis, any given hour-line at one time of the year did not coincide with that produced at the same hour, when the declination of the sun was different, or when another period of the year had arrived. In like manner, in the transparent globe, when the axis is displaced, the two meridians and the axis will not coincide except in two points of the circuit; which effect is produced on the hour-lines of our simple sun-dial by the stick deviating from parallelism to the earth's axis.

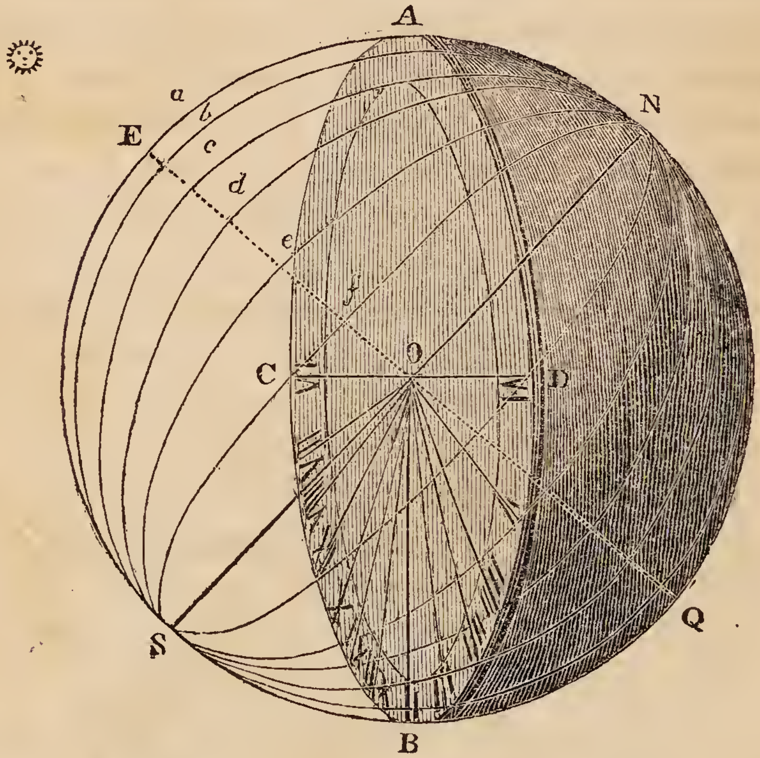
The motion of the earth round the sun being parallel to itself at all times of the year,—if we continue to suppose, for the sake of convenience, the motion of the sun round the earth, it will follow that the plane of the sun's diurnal path is always at right angles to the axis of the earth, and consequently to the shadow-producing part of a dial; thereby generating, as in the case of the transparent globe, effects strictly analogous with those resulting from such an inclination of the stick as made the hour-lines fall respectively in the same and their due places at all seasons of the year.

56. These facts will be further illustrated by the following train of reasoning. Suppose in the hollow globe (fig. 4,) there be placed a plane circular disk of card, or board, or metal, A B C D; such that the axis N S shall go through a hole in the middle of it. Then, if the sun pass round the globe as before, all the lower half of the globe will be concealed from the sun by the disk, during the upper semi-revolution; but the upper surface of the disk will be shaded at different parts by a portion of each meridian and by one half of the axis. Let us now mark what parts of the horizontal disk are shaded by the coincident interposition of the axis and a meridian between it and the sun. We shall find them to be the lines O I, O II, O III, O IV, &c. Now we remarked that, before the disk was introduced, the coinciding positions of the meridians and the axis occurred just the same,

whether the sun had a northern or a southern declination, or was on the equator. We may conclude, therefore, that, in the present instance likewise, the lines on the disk, occasioned by the shadow of the wires and axis, will coincide at each revolution of the sun, whether he have any declination or not; that is, whether it be spring, summer, autumn, or winter.

57. Let us now suppose the position of the disk to be altered, and to be placed vertically in the transparent globe, as

Fig. 5.



at A B C D, fig 5. In this condition of the question, the principle is just the same; but the minor details are modified. In this case the upper half of the axis is concealed, instead of the lower; while the lower half throws its shadow on the lower half of the disk in the manner before described; and thus marks out the permanent hour-lines O VI, O V, O IV, O III, &c., as in the former instance.

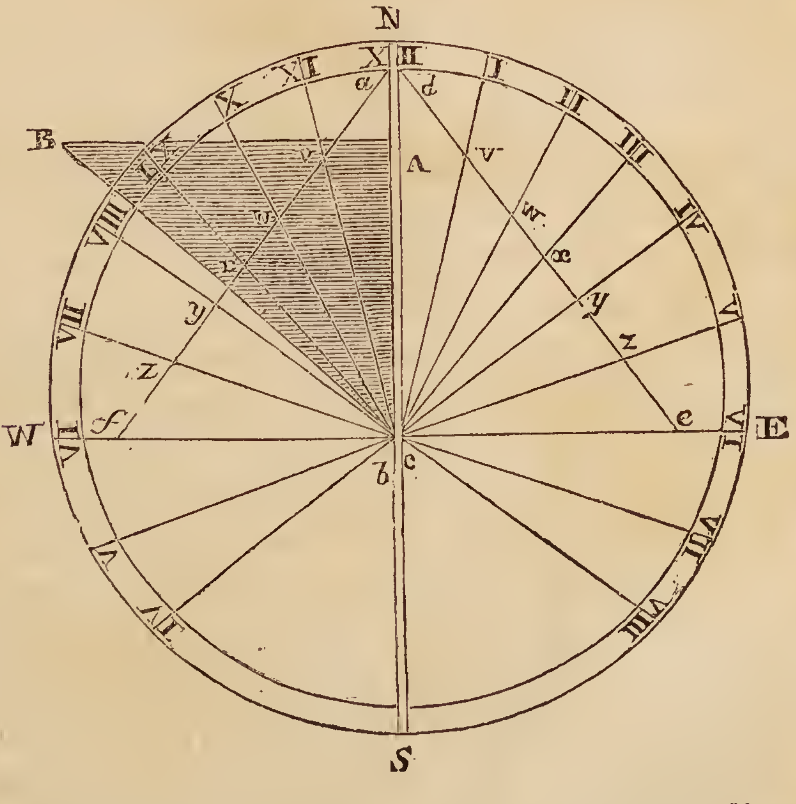
58. We will now endeavour to make this arrangement of parts serve to indicate the hour of the day. The greatest altitude of the sun being at twelve at noon; when he is vertical on the meridian *a*, the shadow of the axis will be thrown on the line O XII, which we therefore call the *twelve o'clock line.* At one hour previous to that, he had been vertical on the meridian *b*; and, as the shadow was at that time cast on the line O XI, we call that the *eleven o'clock hour-line.* In like manner, the lines on which the tenth, ninth, eighth, seventh, &c., hour-meridians cast their shadow, are called the tenth, ninth, eighth, seventh,

&c., hour-lines. The afternoon hour-lines follow a course like those of the forenoon; and thus we get as many hour-lines as there are occultations of the axis by the meridians, while the sun is going half round the globe.

59. If we now imagine the disks, *with the axes fixed to them*, to be taken out of the globe, we have at once two sun-dials, the one *horizontal*, and the other *vertical;* of which the axis is now termed the *style.* The particulars referred to these two disks, form the foundation of all sun-dials; and the grand requisite is a shadow-producing body, strictly parallel with the earth's axis, and therefore perpendicular to the equator. It will, of course, be seen at once that the mode above described is not practically employed in the construction of sun-dials, but is merely used to show the causes, which render it necessary that the shadow should result from a body not deviating from parallelism with the earth's axis.

60. Let us now compare the appearance of the horizontal disk in fig. 4, with the surface of fig. 6; and we shall see that the lines are arranged in a manner precisely similar in the two cases: the difference being only that which is due to an oblique view in the former case, and a direct view in the latter. In fig. 6, there is a triangular portion *b* A B, shaded darker than the

Fig. 6.



rest, and apparently overlapping some of the hour-lines beneath. Let us suppose this to be a thin piece of wood, or metal; and that a hinge or similar contrivance at the side *b* A, enables us to

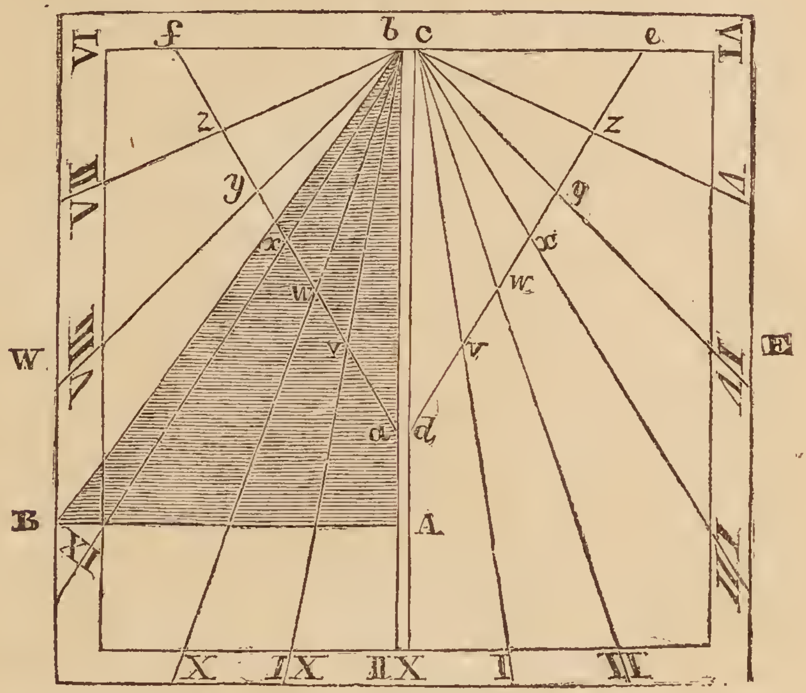
turn up the triangle into a position perpendicular to the plane of the paper. If this be done, we perceive that the sloping edge *b* B of the triangle bears exactly the same relation to the plane of the dial, as the semi-axis N O, fig. 4, does to the horizontal disk: that is, it forms an angle with the plane through which it passes, or on which it impinges, equal to the latitude of the place. The globe at figs. 4 and 5, is represented as rectified* for the latitude of London $=51\frac{1}{2}°$; and the angle *b*, of the triangle *b* A B, is likewise $51\frac{1}{2}°$. If it be asked why the shadow-producing body in the sun-dial is a triangle, instead of a straight wire, representing the axis of the earth,—we reply that it is merely for the convenience of fixing it in the proper position. We remember that, when the stick in our first experiment deviated towards the east or west, it gave erroneous results. Now, in fixing a wire through a board, with an especial condition that it shall have a certain inclined position, we find that great difficulty is experienced in keeping that obliquity in the required direction. We are particular in noticing this, because it is important to bear in mind what portions of the apparatus depend on fixed principles, and what are merely convenient for the purposes of adjustment. Thus, the inclined edge *b* B, of the triangle *b* A B, is an *element* of the sun-dial, but the side A B, is merely the means of lifting up the side *b* B, to the proper altitude; and the side A *b*, serves to prevent a deviation to the east or west, when the triangle is fixed in its proper position for use. The whole triangle *b* A B, is called the *gnomon;* the shadow-marking edge *b* B, is the *style*, which should be sharp and straight; and the support beneath at *b* A, is the *sub-style.*

61. The remarks just applied to figs. 4 and 6, will also avail for figs. 5 and 7. If we conceive the triangle A B *b*, fig. 7, to be raised to a position perpendicular to the plane of the paper, by means of a hinge at the side A *b*, we shall find that the sloping edge *b* B, will bear the same relation to the face of the dial, as the semi-axis O S, bears to the vertical disk in fig. 5; that is, the angle which the axis there makes with the disk will be equal to the angle B *b* A, of the shaded triangle. It will further be seen that, if the two globes be constructed for the same latitude, (as is the case in our figures,) the angle which the axis makes with the horizontal disk in fig. 4, is equal to the latitude of the place; and that which it makes with the vertical disk in fig. 5, is equal to the polar distance, or co-latitude;—

* An artificial globe is said to be *rectified* for the latitude, when its axis is placed parallel with the axis of the earth.

that is, what the latitude wants of 90°. In like manner, the angle *b*, in the triangle of fig. 6, is equal to the latitude of the place; while the angle *b* in fig. 7, is equal to the polar distance, or co-latitude.

Fig. 7.



62. We come now to consider the means, by which the proper distances of the hour-lines on a common sun-dial, are obtained:—seeing that the use of the transparent globe is rather to assist in the comprehension of the principle, than in the construction of the dial. There are *two* methods afforded for the accomplishing of this object; one by a common terrestrial globe, with the aid of the hour-index and the artificial horizon attached to it,—and the other by the use of *scales* ready prepared for the purpose.

63. If, when treating of the phenomena of the disk in the transparent globe, we had supposed the position of the disk to form a different angle with the axis N S, or to have been adjusted to a different latitude, we should have found that the hour-lines XII, XI, X, IX, &c., would, in some cases, have approximated more closely together, and in others, have been separated more widely apart. A consideration of the mathematical law, by which this change of relative position is brought about, has led to the construction of *scales*, by which the proper angular distances can be determined for any given latitude. The principles on which these scales are constructed, result from a formula in spherical trigonometry, which we may pass by, and proceed rather to their practical application.

64. It is known to most persons who use such instruments,

that on *sectors*, and sometimes on *plane scales*, there are, among others, three graduated lines, marked *hours*, *latitudes*, *chords*. These are the three scales employed in laying down the hour-lines of a sun-dial; and, in order to show the use of them to those who may be in possession of mathematical instruments, we give a brief explanation of the mode of application for laying down the hour-lines for different latitudes.

65. Suppose now that a horizontal dial, of which fig. 6 is a representation, is to be constructed. The first thing we have to do is to obtain a perfectly flat surface, and on that surface, when truly level and firmly fixed, to draw a meridian-line, or a line exactly north and south: the best mode of obtaining which we shall speak of hereafter (73). If our triangle, or gnomon, were devoid of thickness, one meridian-line would be sufficient; but, as it will have an appreciable thickness, so much so that one of its upper edges will project the hour-shadow before noon, and the other after noon, we draw two parallel lines, of which the distance from one to the other will be equal to the thickness of the triangle. These lines are represented in the figure by *a b*, *c d*. Cross these lines by another at right angles *f e*, which we will call the 6 o'clock line: this line need not pass through the centre; so that greater space will be obtained for the mid-day hours, which approximate more than those of morning and evening. Then take in a pair of compasses, the latitude of the place (say London $= 51\frac{1}{2}°$) from the scale of latitudes; and with one foot of the compasses at *c*, measure off that distance on *c e*; and with one foot on *b*, measure off the same distance *b f*. We thus obtain the two points *e* and *f*. Then take in the compasses the whole six hours in the scale of hours, and with one foot of the compasses on *e*, let the other foot fall on some point of the meridian-line, which we will suppose to be the point *d*. With the same opening of the compasses, and with one foot on *f*, obtain a similar point *a*. Then draw two right lines *a f*, and *d e*, each of which will be equal to the whole scale of hours. Then setting one foot of the compasses at the beginning of the scale of hours, at XII, and taking the distance from XII to I, lay off that distance on the line *a f*, beginning from *a*, and on the line *d e*, beginning from *d*: this will give us the two points *v*, respectively. Then take the distance from XII to II, and with that opening of the compasses, and from the points *a* and *d*, respectively, set off the distances *a w* and *d w*, on the before-mentioned lines. Then take in succession the distances from XII to III, XII to IV, XII to V, on the scale of hours, and lay off those distances on each of the two lines *a f* and *d e*, as before, beginning from the points *a* and *d*:—

we shall thus obtain likewise the points x, y, z, on either side. The halves and quarters of each hour may be laid down in a similar manner, if desirable. Then draw lines from the point c through all the different points v, w, x, y, z, on the eastern side of the meridian-line; and from the point b through all the corresponding points on the west. Then, if not done at first, with any convenient radius, draw the concentric circles, and mark the ends of the lines with numerals, from VI to XII, and from XII to VI, as in the figure. But, as the sun rises before 6 o'clock in the morning, and sets later than six in the evening, during the summer months, it is necessary to have two more hour-lines on each side. These may be obtained for the morning by continuing the IV and V o'clock afternoon-lines through the points b or c, to the other side of the circle:—thus making the IV and V o'clock morning-lines. In the same way, by continuing the VII and VIII o'clock morning-lines to the opposite side of the circle, we shall obtain the VII and VIII o'clock evening-lines. As the centre of the circle is not at the points b c, from which the hour-lines spring, the noon-day hour-lines are longer, and consequently afford greater space for the shadow at that part of the day, when the dial is most available.

66. We have next to construct the shadow-producing body; which is usually of metal, as being perfectly flat, and not likely to warp. The triangle b A B, represents its form. The angle A is a right angle. The angle b is equal to the latitude of the place; and the angle B, to the co-latitude. It is then to be fixed truly perpendicular on the double line a b, c d. If we suppose, as before, that there is a hinge at the side b A, and that the triangle is turned up on that hinge, the proper position will be at once attained. This being accomplished, if the dial be placed horizontally, and the double line be made to lie evenly between the north and south, the shadow of the sloping edge of the gnomon will take exactly one hour to travel from one line to the next adjoining line, while the sun is above the horizon. Whether it be morning, noon, or afternoon, the termination of each successive hour will find the shadow coinciding with one of the hour-lines. Thus the apparatus becomes a correct indicator of the progress of the hours at all seasons, and will continue so, as long as its mechanism remains in order.

If a horizontal dial, which shows the hour by the upper edge of the gnomon, be made for a place in the torrid zone, whenever the sun's declination exceeds the latitude of the place, the shadow will in proportion *go back* twice in the day, once in the forenoon and once in the afternoon. We read in the Scriptures

that Hezekiah is promised that his life shall be prolonged for fifteen years, and, as a sign, that the shadow of the sun-dial should go back 10°. This was, however, actually a miracle; as Jerusalem was *not* situated in the torrid zone. This remarkable circumstance was "the wonder done in the land," which the Chaldeans, who visited Hezekiah, were anxious to inquire into. (2 Chron. xxxii. 31.)

67. This, then, is a horizontal sun-dial; and, however fancifully or ornamentally such a dial may be made, it depends for its action on principles strictly such as those we have been detailing. But we have now to show that a like routine of operation, with slight modifications, will produce a *vertical* sun-dial. Having drawn the double meridian-line *a b*, *c d*, fig. 7, as before, and the 6 o'clock hour-line *e f*, at right angles to it, at the *upper* part; take in the compasses the *co-latitude* of the place, and set it off on the lines *b f*, and *c e*. Then, as before, with an opening of the compasses equal to the whole length of the scale of hours, set off the distances *a f*, and *d e*; and from *a* and *d*, mark off the hour-points *v*, *w*, *x*, *y*, *z*, as before, on each side. Having drawn lines through all these points from *b c*, we obtain the hour-lines, which are to be marked with numerals, respectively, from VI to XII, and from XII to VI. A difference of direction in the hour-lines must, however, be observed, as compared with those of the horizontal dial:—in the latter the numbers proceed from morning till evening, *from left to right*, or from W by N to E; while in the vertical dial, they proceed from *right to left*, or from W by S to E.

68. It will be seen that the vertical dial affords no means of indicating hours before 6 o'clock in the morning, nor after 6 in the evening. This is because the plane of a vertical dial, being extended, would pass through the east and west points of the horizon; so that the sun can never shine on this dial but between the times just mentioned. We may soon convince ourselves that the wall of a house, however situated, can never receive the sun's rays for more than twelve hours in one day. In winter the time is less, but never is it greater. It is not necessary, therefore, that the vertical dial should be made to indicate a greater range of hours.

69. The angle made by the style of a vertical dial must equal the co-latitude; that is, for London, 38½°. The triangle or gnomon is to be erected, as before, on the double meridan-line *a b*, *c d*; and the style or sloping edge will, at the termination of each successive hour, coincide with the respective hour-lines on the surface of the dial.

70. Thus may a sun-dial, either vertical or horizontal, be constructed by the aid of scales of hours and latitudes; and, if these scales be correctly drawn, this is, perhaps, the most convenient mode of any. There are, however, other modes, derived from different ways of viewing the phenomena. One mode is by geometrical construction; in which the doctrine of similar triangles, and other geometrical theorems, are made available for this purpose. But the nature of this process is more fitted for the improvement of a student, than for the practical construction of dials. Another mode, and the most comprehensive of all, is by trigonometrical analysis; by which the hour-lines are determined, not only for horizontal and vertical dials, but for every position in which a dial can be placed. This forms a striking instance of the power of analysis, when compared with that of pure geometry. A few formulæ are laid down, by which every change of condition is taken into account; and from these formulæ practical tables may be deduced, to suit any particular circumstances. Hence tables have been formed, in which are given the angular distances of the hour-lines from one another; and to show the utility of such tables, we give a portion of one. Let us suppose that we wish to construct a horizontal sun-dial for the latitude of London. We must erect the gnomon as before detailed. We then obtain a correct meridian-line, and a 6 o'clock line at right angles to it. The dialling scales may now be dispensed with, and the hour-lines may radiate from one another, at the following angles: The 1 o'clock and 11 o'clock lines, must each form an angle of 11° 51′ with the meridian-line. The 2 o'clock and 10 o'clock lines each form an angle of 24° 19′ with the same line. The 3 and 9 o'clock = 38° 3′: the 4 and 8 o'clock = 53° 35′: and the 5 o'clock and 7 o'clock = 71° 6′, respectively: the forenoon lines being west of the meridian, and the afternoon lines on the east.

71. But let us now suppose that the dial is to be constructed for any other (latitude in Great Britain; the northern and southern limits of which are nearly in the latitudes of 59° and 50° N. respectively). Having altered the angle of the gnomon, to suit the new latitude, and having obtained a meridian-line and a 6 o'clock line at right angles to it as before, we refer in the following table to the latitude, for which we lay down the angles expressed in the horizontal line of the tables, according to the different hours. If the latitude be between two of those given in the table, we get an angle between the two for any given hour, by observing that the addition which we make to the smaller angle shall be proportional to the excess of the latitude above the lower of the two in the table.

Latitude.	11 A. M. 1 P. M.	10 A. M. 2 P. M.	9 A. M. 3 P. M.	8 A. M. 4 P. M.	7 A. M. 5 P. M.
50°	11° 36′	23° 51′	37° 27′	53° 0′	70° 43′
51	11 46	24 10	37 51	53 23	70 59
52	11 55	24 28	38 14	53 46	71 13
53	12 5	24 45	38 37	54 8	71 27
54	12 14	25 2	38 58	54 29	71 40
55	12 23	25 19	39 19	54 49	71 53
56	12 31	25 35	39 40	55 9	72 5
57	12 40	25 50	39 59	55 27	72 17
58	12 48	26 5	40 18	55 45	72 28
59	12 56	26 20	40 36	56 2	72 39

The 6 o'clock lines, being, of course, in every case 90° from the meridian, are here omitted.

72. The method of laying down these angles is either by a graduated instrument, such as a *protractor*, or by means of a *scale of chords*, which may be found on every *scale*, so called, in cases of mathematical instruments. In every circle the chord of 60° is equal to the radius. If, therefore, from the centre of the dial-plane, we describe a circle having for its radius the distance from 1° to 60° on a scale of chords, the angular positions of the hour-lines can be determined by cutting off successive segments of that circle by successive chords, all beginning at the same point; the numerical values of which chords must be the same as in some one of the cross-lines of the table given above. The angles of the gnomon may be determined and laid down in a similar manner.

73. An important element in the construction of dials, is the adjustment of the meridian-line. If this be erroneously laid down, all the rest will be in error likewise. Various means, more or less favourable for attaining the object in question, may be adopted; such as the compass, observation of the polar star, &c.; but we will describe one which is easy to complete, and which seems to deserve most dependance, in practice, as its accuracy may be put to a daily test, if necessary.

Suppose that we are about to erect a horizontal dial on the pedestal C, fig. 8. The first thing we have to do is to ascertain that the upper surface, B, is perfectly horizontal. This can be done by means of a spirit-level; and no other process is to be commenced until this adjustment is attained; for, though the style may be parallel with the axis of the earth, and the shadow be duly projected, yet this shadow cannot be correctly received upon the plate, if the plate make an angle with the horizon;

that is, the hour angles must be calculated for the inclination of the plate. But supposing a level to be obtained, draw three or four concentric circles from any point near the middle of the

Fig. 8.

plane B; and at the centre of these circles, set up a perpendicular object, such as a wire or stick *b*. This wire must be of such a height, that the top of its shadow shall fall among the circles, for several hours during the middle of the day. In order to attain perpendicularity in the wire, the two legs of a pair of compasses may be applied, one to any one of the circles, and the other to the top of the wire. If such distance remain equal all round, the wire is quite perpendicular. Suppose now that, when

the sun is at A, say at about 10 o'clock in the forenoon, the shadow of the top of the wire or stick exactly reaches to the point a in the second circle. We then make a mark to indicate that point; and look out for the period in the afternoon when the top of the shadow shall again coincide with some part of the same circle. We will suppose that at 11 o'clock it coincides with the third circle, and at noon with the innermost circle. After which, travelling round, it will again get outward and successively touch the next two circles. At two o'clock, when the sun is at A′, the end of the shadow will touch the second circle at a', which it had touched at a about four hours before. If now we bisect the distance between a and a', we shall obtain the point m; and if we draw a line $m\ m'$ through the foot of the stick or wire, we shall obtain a meridian-line. The principle on which this method is founded is, that the sun is exactly at the same height at any number of hours after noon, as he was at the same number of hours before noon; and although this is not rigorously correct, in consequence of the sun's gradual change of declination, yet it is sufficiently so for all practical purposes. Nevertheless, this method of finding the meridian-line will be most accurate at the time of the summer solstice, when the change of the sun's declination is almost imperceptible for several days. The sun, at the two equal altitudes, produces equal lengths of the shadow of the wire; and, by bisecting the angle between those two shadows, we obtain the noon-day shadow, which is in the meridian. The two shadows $a\ a'$ are respectively thrown at equal portions of time from the sun's crossing the meridian, as may be seen by taking the sun's altitude at those times with a quadrant.

74. It must be borne in mind that, when the dial is truly fixed, the shadow of the style will indicate the time one minute faster in the morning, and one minute slower in the afternoon, than the *true* solar time. The foremost edge of the sun in the morning, and the hinder edge in the afternoon, is straight with the line of shadow on the dial-plate. Now the reckoning for *true* solar time must refer to the centre of the sun; and as he is about $\frac{1}{2}°$ in breadth, he takes about two minutes to traverse that space in the heavens. Hence also it is found how it is, that the shadow of the gnomon has no motion for one minute before, and for one minute after, the sun's centre passing the meridian.

75. We have thus far treated of the elements of a sun-dial: but such dials as we have spoken of are either *horizontal* or *vertical*. When, however, the principle of their construction

is well understood, any position of a dial may be chosen at pleasure, and a correct adjustment of parts attained.

76. When a dial faces the south, such as the vertical dial which we have been considering, but *inclined* instead of vertical, it is called an *inclined south dial;* and takes a modification in its construction, depending conjointly on the direction towards which it leans, and the degree of its inclination. When the top edge of such a dial leans over towards the north, it is called a *reclining* dial; but if it lean over towards the south, it is an *inclining* or *proclining* dial:—the terms *reclining* and *inclining* or *proclining* being considered relatively to the position of the sun.

77. If then a *reclining* dial form an angle with the perpendicular equal to the co-latitude of the place, the plane of the dial is parallel with the axis of the earth; and, as the style of the gnomon is also parallel with the axis of the earth, the style and the dial-plane are parallel with each other. By this circumstance, the form of the gnomon must be changed from a triangle to a rectangle; and the hour-lines must be changed from having an angular deviation from each other, to a position of parallelism: indeed the style and all the hour-lines become parallel. This form obtains for it the name of a *polar* dial; because it presents just the same features as a vertical dial adapted for the North pole. The distances of the hour-lines of 1, 2, 3, 4, and 5 o'clock, are respectively the tangents of 15°, 30°, 45°, 60°, and 75°, the height of the style from the dial being equal to radius. Dials of this form are only useful during the middle of the day, on account of the great rapidity with which the distances of the hour-lines from each other increase, as the time deviates from 12 o'clock at noon. This dial is of two kinds, *upper* and *lower;* the former having its face towards the zenith, the latter towards the nadir. The *upper* polar dial shows the hours between 6 o'clock in the morning and 6 in the evening; the *lower* points out the time before 6 in the morning, and after 6 in the evening, and is available only in summer.

78. Let us now suppose that the dial, instead of reclining from the vertical position towards the north, inclines towards the south, or becomes an *inclining* or *proclining* dial. We shall find that the positions of the style and hour-lines, with regard to each other, must be continually varied, as the inclination increases, until we arrive at a point, which is, in every respect, the reverse of that just described as obtaining with the *polar* dial. When the leaning towards the south is carried on, until the plane of the dial forms an angle with the perpendicular,

equal to the latitude of the place, then will the plane of the dial coincide with the plane of the equator; and, as the style of the dial is constantly parallel to the earth's axis, it follows that, in the present case, it will stand out perpendicularly to the dial. Another consequence of this position is, that all the hour-lines are equidistant from each other. A dial, therefore, properly constructed for this position is, in fact, a wheel or ring, with twenty-four equidistant radii proceeding from the centre to the circumference; of which radii eight are not wanted in practice. The gnomon is a straight wire or peg, running out from the middle of the wheel, like an axis. This form of dial is called an *equinoctial* dial; because it is the form of a vertical dial, used at the equator, or equinoctial line. Of these dials, it should likewise be observed that, if the hour-lines be made to look towards the heavens, it is called a *superior* dial; if towards the earth, an *inferior* dial. The former shows the hours of the day, only from the vernal to the autumnal equinox; and the latter from the autumnal to the vernal equinox. At the equinoxes, this dial can be of no use; for, while the sun has no declination, the plane of this dial being extended would pass through the sun's centre, so that no shadow would be projected on either face of the dial.

79. We have hitherto supposed the dial to present only its *edges* to the east and west points. We will now consider the modification necessary to adapt a dial for other positions. Let us suppose, for instance, that a dial has to be fixed vertically against the east wall of a house, so as to face the early morning sun. Now, in this case, a little consideration will show that the plane of the dial will be in the plane of the meridian; for whatever exactly fronts the east (which we have supposed the plane of this dial to do,) or the west, is in the plane of the meridian. But we know, also, that the axis of the earth is always in the plane of the meridian, and that the style of the dial must be parallel to that axis. From all these circumstances, therefore, it results, that the style of the dial must be parallel to the plane of the dial, a condition which we found necessary in the polar dial. The similarity between them extends further. The hour-lines of the east dial, like those of the polar dial, are parallel to one another, and to the style of the gnomon. It further follows from all this, that a line drawn perpendicularly through all the hour-lines, would be in the plane of the equator; that is, would deviate from the vertical position by an angle equal to the latitude of the place.

80. If we now consider that the west face of a wall is as

much in the plane of the meridian as the east face, we shall be prepared to observe that the same general form of dial would serve for the one as for the other; the only points of difference being these: that a line drawn perpendicularly through all the hour-lines inclines upwards from the right to the left in the east dial, but downwards from the right to the left in the west dial; and, that the hour-numbers from 12 to 9, go upwards from left to right in the west dial, and from left to right downwards in the east dial, reckoning from 3 to 12. These dials, as also all whose planes do not directly face the north or south, are called *decliners.* It must also be remarked that the east dial is of no use after noon, and the west dial does not avail before noon.

81. We have seen that a dial, whose *edges* were towards the east and west, might incline or recline, as well as be vertical. We shall also find that a dial which faces the east or west, may likewise incline or recline. This species of dial is named *deinclined;* that is, when the dial both declines and inclines,—or both declines and reclines; in which cases the plane of the dial is neither in the meridian, nor at right angles to it; and it is neither parallel nor perpendicular to the earth's axis. It follows, therefore, that the style, being parallel with the earth's axis, cannot be parallel with the plane of the dial, but has a certain degree of obliquity to it. This obliquity is attended by a change in the positions of the hour-lines with respect to one another. They are no longer parallel, but all emanate from that point where the end of the style intersects the plane of the dial. This change varies in amount according to the extent of the obliquity occasioned by the position of the dial. If the inclination be carried on until the dial assumes the horizontal position, the variation of the form of the gnomon will assume all the features from parallelism to an angle equal to the latitude; and the relative positions of the hour-lines will suffer an equal amount of variation. But all this sort of dialling is necessarily very rare.

82. Let us now suppose that the dial, instead of facing either of the four cardinal points of the horizon, faces a secondary point—say, the south-east; but that it still retains a vertical position. We shall see that the style, in order to be parallel with the earth's axis, must not be parallel with the plane of the dial, as in the east and west dials; nor must it be inclined to it at an angle equal to the co-latitude, as in the south vertical dial; but that it must occupy a position between those extremes. The hour-lines, likewise, will not be parallel with each other, as in the east and west dials; nor will they

approach so near to the wheel-like appearance, as in a south dial; but will spread out like a fan, the intervals between the radii of which will follow a certain law according to the latitude of the place. Such dials as these are called *erect-declining south-east* dials.

83. This dial may likewise be conceived to incline or recline from the vertical position, as in the case of the others; and the phenomena presented by it, and consequent upon that inclination, or reclination, will follow a law as strictly dependent as the former, on the conditions of the case, but much more complicated, in consequence of the position of the dial, being at once a deviation from the vertical, the horizontal, the meridional, the polar, and the equinoctial position. The same mode of reasoning will, of course, apply to a dial, which faces any other point of the compass than the eight principal points. The reader must bear in mind that the style of the gnomon must always be parallel with the axis of the earth, and he will then have no difficulty in understanding that, as the hour-lines are but types of the shadow of the style, the positions of those lines with respect to one another, and to the style, must vary greatly, according as the plane of the dial is parallel, or perpendicular, or more or less inclined to the earth's axis. This last sort of dial is called *declining-inclining*, or *declining-reclining*, with the name of that point of the compass, which it faces, affixed to it.

84. Such are the chief modes, by which the ancients made the daily motion of the sun serve as a measure of the progress of time. The different forms of time-markers which we have described, came into use at different eras, and among different nations. Many of the foregoing dials are almost entirely theoretical; that is, are exemplifications of what would be the mode of construction of a dial for such and such a situation; but the necessity for which situations seldom, if ever, occurs. This remark applies likewise to a variety of forms and modifications of the sun-dial, which have exercised the ingenuity of diallists:—but into these we shall not enter; for there is either a nicety of construction necessary, which puts them out of the reach of most persons, or else there are inconveniences attending the use of them. We will not, however, omit to mention one species of dial, which is often set up on lawns, before country-houses, and is not only an agreeable ornament, but a memento to the Christian and philosopher—the symbol of his salvation, warning him of the flight of time, and the necessity for using it rightly.

The Cross-dial stands obliquely on a pedestal, and the top of

the cross points southward; the plane of the body of the cross coinciding with the plane of the equinoctial. The consequence of this position is, that the edges of the arms of the cross, which edges are at right angles to the plane of the cross, as it coincides with the equinoctial, are parallel with the earth's axis, and project shadows, which mark the hours respectively upon different parts of the instrument, as the sun performs its circuit. This dial agrees, therefore, in principle, with an equinoctial dial.

85. There are now some important circumstances in the deduction of time from a sun-dial, which must not be overlooked. In order to make ourselves understood, it will be necessary to consider a little more closely, the motion of the sun in the ecliptic.

The ecliptic, or the apparent path which the sun describes round the earth in a year, is not quite a circle, but an ellipse; of which the earth is in one focus, and therefore not at the same distance from the sun throughout the year. Now, from the difference between a circular and an elliptic path round the earth, results this consequence; that the sun does not move equably in this orbit, but varies in his velocity, according to his greater or less distance from the earth. Again, the ecliptic, or sun's path, as we have before seen, is not in the plane of the equator, but inclined $23\frac{1}{2}°$ to it; and hence arises another source of irregularity; for, as the angular distance between two meridians on the earth (which distance is 15°) is measured on the equator, an angular distance of the same quantity measured in another plane inclined to the former, does not give the same results. Hence, were the ecliptic a circle, and consequently the sun's motion to describe equal arcs in equal times, there would still be a discrepancy due to the obliquity of the two planes, the equator and the ecliptic. But, as we know that the ecliptic is an ellipse, and that therefore the sun does not describe equal arcs in equal times (as viewed from the earth), it follows that there are two disturbing causes in action at once; each of which tends to make a real solar hour either greater or less than a mean or equable hour. But, as those two disturbing forces are unequal, and act independently of each other, it often happens that one compensates the error of the other by an equal error in the opposite direction; while at other times both kinds of error combine to produce a maximum deviation in one direction. The manner in which the operation of these errors is shown in the measurement of time is this:—we suppose 24 meridians to go round the earth, each extending from pole to pole, and to be equidistant; which gives an angular opening of 15° between two

consecutive meridians on the equator. Now, if the sun appeared to describe 15° of an equatorial circle every hour, the error would not exist. But he does not; sometimes for many weeks together, he will describe a minute fraction more than 15° in a mean hour, while at other times he describes a little less than 15° in the same time. This acceleration or retardation is, for three or four days, so inconsiderable, that it may safely be disregarded in common operations; but it accumulates to an appreciable quantity in process of time, and must then be taken into account in making observations with the sun-dial.

86. The modern clocks and watches, which have now almost superseded the sun-dial so far as the business of life is concerned, though the latter is still profitably employed to prove the accuracy of the former,—due regard being had to the periodical difference between the watch and dial,—are made to mark precisely equal hours at every part of the day, and at every season of the year. The short hand of a good clock makes two revolutions in a *full* day, and the long hand makes twenty-four; each of which occupies respectively, exactly the same time as any one of the others. Now, as two consecutive solar days never deviate from each other in length more than half a minute, the difference might be disregarded as respects that half-minute; but when the error has accumulated, so that the proper noon, as indicated by a sun-dial, is more than sixteen minutes before or after the true noon, as indicated by a good clock, it becomes necessary to know at what parts of the year the sun is in such a position as to give an error of that amount, when compared with the clock. Accordingly, tables have been computed, which show the amount of time which is to be added to, or subtracted from, sun-dial time, in order to bring it to clock, or mean time; this adjustment being necessary, as most commercial, judicial, and domestic arrangements, are regulated by clock-time. These tables are called tables of the "*Equation of time;*" and are usually found in almanacs. In some of them, the notification, "*Clock too fast,*" or "*Clock too slow,*" at the head of a column, shows the time to be added to, or subtracted from, the solar time; but in others the exact clock time when the sun-dial indicates 12 o'clock at noon, is given. If the equation-table point out *clock before sun*, we must add the difference; if *clock after sun*, we must subtract: the time given by the dial, which is the solar time, being to be adjusted to mean time, which is such as a good clock gives.

87. The light of the moon may be made the means of indicating the progress of time, by the following contrivance.

On a perfectly flat surface, describe a circle, and divide its circumference into $29\frac{1}{2}$ equal parts. Concentric with this, describe a smaller circle, divided into 24 equal parts. The inner circle must be separate from the outer, so as to move round a central pivot. This pivot may be a small wire or peg, acting as the style of an equinoctial dial; which style is at right angles with the plane of the dial. The plane, with the two concentric circles, must be fixed in the plane of the equator, as an equinoctial dial; and the 12 o'clock line brought to the moon's age. In order to do this, the outer circle must be numbered from 1 to $29\frac{1}{2}$, and the inner from 1 to 12, twice over, for the 24 hours of the full day. The moveable circle is to be turned round until the 12 line coincides with the day of the moon's age, as marked on the outer circle; and the shadow of the wire will give the time as marked on the inner circle.

There are also other modes, by which the motion of the moon may be made, to a certain degree, available for the same purpose; but none of them are deserving of much confidence, on account of the very variable nature of the moon's motion.

88. We have not now the means of knowing positively, when sun-dials were first invented; but the evidence of their existence extends to a period of at least eight hundred years before the Christian era. It is said that the Chinese had a treatise in their language on the clepsydra and gnomon, about 300 B.C. But we learn from history that sun-dials were made in Greece six centuries before the Christian era. The Greeks obtained their knowledge of this art from the Chaldeans; from whom also the Jews had obtained instruction of this sort, or dials ready made to hand, 713 B.C. The dial was first introduced at Rome in the year 293 B.C., when the day came to be divided into hours. In the year 259 B.C., a dial was brought by the Roman victors from Catana, in Sicily; and was set up in the forum. It was found not to give correct time; and no wonder; for it was computed for the latitude of Catana, not of Rome; the former being $37\frac{1}{2}°$ N., and the latter $41\frac{3}{4}$ N.

There was one circumstance which rendered a change in the mode of constructing dials necessary among those early nations in which the *variable* hours were employed; where the period from sunrise to sunset was divided into 12 hours, as also the period from sunset to sunrise; a necessary consequence of which division was that, at some periods of the year, the day-hours were longer than those of the night, and at other periods shorter. Now, in order to make the sun-dial a correct measure of time, it was necessary that it should indicate the longer hours as well

as the shorter. So that a continual process of adjustment must have greatly narrowed the utility of the instrument; but have led, in the course of time, to the adoption of equal hours.

89. The use of sun-dials is quaintly alluded to in a fragment of a comedy by Plautus, in which a gluttonous person exclaims against sun-dials in these terms: "May the gods confound the fellow who first invented hours, and placed the dial here, which doles out the day piecemeal to me—an unhappy wretch! For when I was a boy, my belly was my dial, and it was by far the best, and truest of them all. I ate whenever it warned me; unless there was nothing to be had;—but now, whatever there may be, we must not have it unless it pleaseth the sun. Indeed, since the town was filled with dials, the greater part of the people crawl about starving with hunger." This curious kind of objection to the use of time-measuring instruments very naturally sprang up in the process of civilization among the Romans, when regular hours were appointed for meals, and order had succeeded to the rudeness and irregularity of barbarism. The foregoing was probably written about 200 B.C., when sun-dials began to be common in Rome.

90. The employment of sun-dials has been at all times more prevalent in those countries which approach near the equator, than in those of a more northern position. The reason for this is two-fold: 1st, The nearer any country is to the equator, the more equable is the length of time that the sun is above the horizon; and therefore a sun-dial is nearly as useful in winter as in summer, in such places; but, in more northern positions, the dial becomes of much less value in winter than in summer, because in winter the sun is above the horizon for a much shorter period than he is below it; 2ndly, When the meridian-altitude of the sun is small (as it is in winter in northern latitudes,) the rays of solar light approach the position of the observer so obliquely, that they are frequently hazy, or absorbed altogether by the thick cloudy stratum of atmosphere through which they must pass before they can reach him; whereas, in equinoctial climates, the sun's position is throughout the year so soon elevated, that the rays have a comparatively thin and pure stratum of air to pass through. This, together with the more general clearness of the sky, allows the sun's light to fall almost uninterruptedly on the earth; by which the dial is made available, for a greater number of hours, and to greater effect, than in a country further removed towards the poles.

91. Here we take leave of the sun-dial; for it has almost

taken leave of us. Its empire is now for the most part given up to the clock and the watch,—those admirable specimens of the ingenuity of man; admirable not only on account of the useful services which they render us, but also as showing, that, although man can never equal the exquisite productions of nature, yet he may, by trying to learn the use of the tools with which Nature works, or rather, which she places within our reach, produce specimens of industry and ingenuity which will render him both pleasure and profit.

92. Yet, almost superseded as it is by superior instruments, we cannot but consider the sun-dial as an instructive instrument to the student who is desirous of learning the causes of things. The principles, on which the sun-dial is constructed, and on which it acts, are at once simple and beautiful; and are bound up with some of the most important doctrines of Astronomy. There is, besides this, a permanent value given to the sun-dial, arising out of the circumstance that it affords a never-failing test of the accuracy of clocks and other time-measuring instruments. Works of art are subject to all the mutations which belong to the productions of man; and, however admirable the construction of watches and chronometers may be, these lose much of their value unless they agree with one another, or unless there exist indications by which one watch or chronometer may be compared with another. The apparent motion of the sun in the heavens, or the representation of that motion by the sun-dial, affords a standard by which other time-measuring instruments may be corrected, and made to agree with one another; and so far, great utility may be found in a good sun-dial, well fixed,—if not so much for the regulation of the practical concerns of daily life, yet with a view to test those little machines which the advanced state of society obliges us constantly to refer to. These observations apply with practical force to a person situated in retired country parts, where he may not be able to seek for correct time from a large town, and where, consequently, but for the sun-dial, he must take an opinion about time from those who do not understand the course or measurement thereof.

93. The clepsydra, the hour-glass, and the sun-dial, were the means by which the philosophers of the young world recorded their hourly observations of the heavenly bodies, and thus sowed the seeds of that scientific knowledge which subsequent ages have cultured into maturity. The working-tools of an infant fraternity are objects of interesting retrospect to the same fraternity, when it has acquired better processes and

improved implements. Let us, therefore, in the midst of our admiration of a chronometer or a watch, reserve a word of praise for those simpler, but less convenient modes, by which the men of other days measured time,—that valuable element, which we can all understand, but none of us can well define.

94. Let us hope that, when the reader's attention is directed to the sun-dial, he will sometimes bear in mind the simple and beautiful language of the venerable poet, which we have prefixed as a motto to the second section of this paper:—we conclude with the remaining verses of the poem:—

Another race succeeds, and counts the hour,
Careless alike; the hour still seems to smile,
As hope, and youth, and life were in our power;
So smiling and so perishing the while.

I heard the village-bells, with gladsome sound,
(When to these scenes a stranger I drew near,)
Proclaim the tidings of the village round,
While mem'ry wept upon the good man's bier.

Even so, when I am dead, shall the same bells
Ring merrily, when my brief days are gone;
While still the lapse of time thy shadow tells,
And strangers gaze upon my humble stone!

Enough, if we may wait in calm content
The hour that bears us to the silent sod;
Blameless improve the time that Heav'n has lent,
And leave the issue to thy will, O God.

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